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WIND-TUNNEL INVESTIGATION OF THE EFFECTS OF SLOT SHAPE AND FLAP LOCATION ON THE CHARACTERISTICS OF A LOW-DRAG AIRFOIL EQUIPPED WITH A 0.25-CHORD SLOTTED FLAP

By Ralph W. Holtzclaw and Yale Weisman

Ames Aeronautical Laboratory
Moffett Field, California

NACA

WASHINGTON

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

MEMORANDUM REPORT

for the

Bureau of Aeronautics, Navy Department

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SUMMARY

An investigation was made to determine the effects of slot shape and flap location on the characteristics of an NACA 66,2-216 (a = 0.6) airfoil equipped with a 0.25-chord slotted flap to provide a basis for the study of drooped ailerons. Two slots were investigated and practical flap paths were selected for each. One slot had a rounded entry; the other had an entry designed to reduce the gap with the flap retracted to a practical minimum.

Slot shape was found to have a negligible effect on the maximum lift coefficient if the flap was properly located. With the flap deflected, the rounded-entry slot had lower drag coefficients for intermediate lift coefficients than the minimum-gap slot. For either slot, the increment of section pitching-moment coefficient caused by flap deflection was approximately proportional to the increment of section lift coefficient.

With the flap retracted the minimum-gap slot had a lower minimum profile-drag coefficient, low-drag characteristics over a larger range of lift coefficients, and slightly higher section pitching-moment coefficients than the rounded-entry slot.

The flap locations for maximum lift and minimum drag with respect to the airfoil (flap deflected) were further aft and higher with the minimum-gap slot than with the rounded-entry slot.

INTRODUCTION

For some time the National Advisory Committee for Aeronautics has been investigating airfoils equipped with high-lift devices for the purpose of improving the performance characteristics of these airfoils. The results of tests of low-drag airfoils equipped with slotted flaps have been presented in reference 1. The results of reference 2 show that, on conventional airfoils, openings in the airfoil surface caused a measurable increase in drag of the airfoil for the condition of high-speed flight. It was also found that the location of the flap had a large influence on the magnitude of the maximum obtainable lift coefficients.

To provide a basis for a study of the characteristics of drooped ailerons, the effects of slot shape and flap location on the section aerodynamic characteristics of a low-drag airfoil were determined and practical flap paths were selected.

The tests were conducted in the 7- by 10-foot wind tunnel No. 1 of the Ames Aeronautical Laboratory.

COEFFICIENTS AND CORRECTIONS

The coefficients used in the presentation of results are as follows:

c_l section lift coefficient (l/qc)

Δc_l increment of section lift coefficient due to flap deflection

c_{d_o} profile-drag coefficient (d_o/qc)

c_m section pitching-moment coefficient about quarter chord of section with flap in neutral position (m/qc^2)

Δc_m increment of section pitching-moment coefficient due to flap deflection

where

l section lift

d_o profile drag

m section pitching moment

q dynamic pressure $(\frac{1}{2}\rho V^2)$

c airfoil chord including flap

and

α_0 angle of attack for infinite aspect ratio, degrees

δ_f flap deflection, degrees

The lift, profile-drag, and pitching-moment coefficients have been corrected for tunnel-wall effects. A comparison of force-test results with pressure-distribution measurements of section lift and pitching-moment coefficients indicated negligible end-plate effect on these coefficients. The end-plate effect on the profile-drag coefficients was determined by a comparison of measurements of the loss of momentum in the wing wake with the force-test measurements. All the results have been corrected for this effect.

MODEL AND APPARATUS

The airfoil was constructed of laminated mahogany to the NACA 66,2-216 (a = 0.6) profile of 4-foot chord. The airfoil ordinates are given in table I. The aft 0.35 chord of the airfoil was made removable to allow the testing of different slots. The airfoil and flap were equipped with a single row of pressure orifices built into the upper and lower surfaces at the midspan station. The orifice locations are listed in table II. The flap was constructed of laminated mahogany to conform to the profile of the normal airfoil section. The flap ordinates are given in table III. The details of the two slots tested are shown in figure 1. Slot A had a rounded entry, while slot B had an entry designed to reduce the gap with the flap retracted to a practical minimum. The slots will be referred to by their letter designations throughout the remainder of this report.

TEST INSTALLATION

The airfoil was mounted vertically in the 7- by 10-foot wind tunnel No. 1 completely spanning the height of the tunnel, as shown in figure 2. Turntables, 6 feet in diameter, were attached rigidly to the model and mounted flush with the tunnel floor and ceiling. Provisions were made for changing the angle of attack, flap deflection, and the normal and chordwise location of the flap while the tunnel was in operation.

TESTS

The tests were condutcted at a dynamic pressure of 50 pounds per square foot, corresponding to a Reynolds number of approximately 5,100,000 (Mach number of approx. 0.19). Lift, drag, and pitching-moment measurements were made throughout the useful angle-of-attack range for a constant flap deflection and position. An average of 20 flap locations was investigated with each slot for flap deflections of 0°, 10°, 20°, 30°, 40°, and 50°. A very limited number were also investigated for 45°. Due to the high loads imposed upon the balance system and the nature of the stall of the model, very few test points were obtained after the stall. The maximum lift, however, was measured for every flap location.

RESULTS AND DISCUSSION

The results of tests to determine the effects of slot shape and flap location on the characteristics of a low-drag airfoil equipped with a 0.25-chord slotted flap are presented as contours of the nose position of the flap for constant lift and drag coefficients. The reference point for these contours was taken as the intersection of the airfoil chord line and the flap nose with the flap retracted (station 0.755 chord on the chord line).

The variation of maximum lift coefficient with flap location and deflection is shown in figure 3 for slot A and in figure 4 for slot B. The flap location with respect to the airfoil for maximum lift at a given deflection is further aft and higher with slot B than with slot A. The maximum measured lift coefficient was 2.89 with slot A (fig. 3(d)) and 2.90 with slot B (fig. 4(d)). The difference between these values is within the experimental accuracy of the tests. Both maximum values were measured with 40° flap deflection. Due to time limitations, the maximum possible lift coefficient was not measured for <u>all</u> flap deflections.

The lift coefficients for which the contours of constant drag coefficients are presented were selected to cover the range of lift coefficients for which the drag coefficient is decreased by flap deflection. Those data are presented for various flap deflections with slot A in figure 5 and with slot B in figure 6. As in the case of the maximum lift coefficient, the flap location for minimum drag, at a given deflection and lift coefficient, is farther aft and higher with slot B than with slot A. The measured minimum drag coefficients for intermediate lift coefficients are lower with slot A than with slot B. This is probably the result of smoother flow through the slot with the rounded entry.

Complete aerodynamic characteristics of the airfoil with slot A are shown in figure 7 for the flap path described by figure 8. For this path the flap is simply hinged about a point 80.25-percent wing chord from the leading edge of the airfoil and 8-percent wing chord below the chord line. The characteristics of the airfoil with slot B are shown in figure 9 for the flap path described by figure 10. For this path the flap nose moves aft and up along a straight line with the flap deflection increasing as the flap is extended. These flap paths were chosen with a view toward a practical installation. Sufficient data have been presented in the form of contours (figs. 3 to 6) to estimate the maximum lift and drag characteristics for alternate flap paths.

Envelope polars for the two flap paths are shown in figure 11. Data for the plain airfoil as taken from reference 1 are also shown for comparison. As shown by this figure, lower profile drag was obtained with slot A than with slot B for lift coefficients from 0.65 to 2.65. The irregularities in these curves are caused by a shift of the low-drag range with flap deflection (figs. 7 and 9).

A comparison of the maximum lift-coefficient increments due to flap deflection for the two flap paths is shown in figure 12. For further comparison, curves are shown for the maximum lift-coefficient increments measured with the two slots. As shown by figure 12, and figures 3 and 4, the maximum measured lift coefficient was obtained at a flap deflection of 40° for both slots. It should be re-emphasized that a limited number of points were taken for the contours so that the maximum obtainable lift was not measured for every flap deflection, particularly for the low deflections.

As illustrated by figure 13, the increments of section pitching-moment coefficient due to flap deflection are approximately proportional to the increments of section lift coefficient. The variation shown is for zero angle of attack for the selected flap paths.

A comparison of the section aerodynamic characteristics of the airfoil, with the slotted flap undeflected, with the characteristics of the plain wing as taken from reference 1 is shown in figure 14. As shown by this figure, the drag increment due to the addition of the slot was considerably higher with slot A than with slot B. The minimum profile-drag coefficient was 0.0055 with slot A and 0.0042 with slot B as compared to 0.0040 for the plain airfoil. The range of lift coefficients for which low-drag characteristics were apparent was larger with slot B than with slot A (fig. 14).

CONCLUDING REMARKS

The results of the tests to determine the effects of slot shape and flap location on the characteristics of a low-drag airfoil equipped with a 0.25-chord slotted flap indicated the following:

1. Slot shape had a negligible effect on the maximum lift coefficient for the two slots tested if the flap was properly located.

2. For intermediate lift coefficients with the flap deflected, the rounded-entry slot had lower profile drag.

3. For either slot the increment of section pitching-moment coefficient due to flap deflection was approximately proportional to the increment of section lift coefficient.

4. The addition of the minimum gap slot to the plain airfoil caused an increase in the section profile-drag coefficient of 0.0002 (flap retracted), while the addition of the rounded-entry slot caused an increase of 0.0015.

5. Low drag was obtained for a larger range of lift coefficients with the minimum-gap slot (flap retracted) than with the rounded-entry slot.

6. The pitching-moment coefficients were slightly higher with the minimum-gap slot (flap retracted) than with the rounded-entry slot.

Ames Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Moffett Field, Calif.

REFERENCES

1. Jacobs, Eastman N., Abbott, Ira H., and Davidson, Milton: Preliminary Low-Drag-Airfoil and Flap Data from Tests at Large Reynolds Numbers and Low Turbulence. NACA ACR and Supplement, Mar. 1942.

2. Wenzinger, Carl J., and Harris, Thomas A.: Wind-Tunnel Investigation of an NACA 23012 Airfoil with Various Arrangements of Slotted Flaps. NACA Rep. No. 664, 1939.

TABLE I.– ORDINATES FOR NACA 66,2-216 (a = 0.6) AIRFOIL
[Stations and ordinates in percent of airfoil chord]

Upper surface		Lower surface	
Station	Ordinate	Station	Ordinate
0	0	0	0
.371	1.242	.629	-1.112
.607	1.501	.893	-1.319
1.091	1.886	1.409	-1.608
2.317	2.615	2.583	-2.127
4.794	3.701	5.206	-2.869
7.284	4.563	7.716	-3.441
9.781	5.308	10.219	-3.934
14.788	6.500	15.212	-4.702
19.806	7.428	20.194	-5.290
24.832	8.155	25.168	-5.741
29.862	8.708	30.138	-6.030
34.897	9.098	35.103	-6.312
39.936	9.355	40.064	-6.462
44.978	9.471	45.022	-6.523
50.023	9.431	49.977	-6.483
55.073	9.224	54.927	-6.336
60.141	8.800	59.859	-6.048
65.191	8.084	64.809	-5.574
70.198	7.068	69.802	-4.866
75.181	5.889	74.819	-4.037
80.148	4.585	79.852	-3.107
85.106	3.265	84.894	-2.177
90.061	1.937	89.939	-1.235
95.021	.762	94.979	-.432
100	0	100	0
L.E. radius: 1.575		T.E. radius: 0.0625	

TABLE II.— PRESSURE-ORIFICE LOCATIONS IN THE NACA 66,2-216 (a = 0.6) AIRFOIL AND IN THE 0.25-CHORD SLOTTED FLAP

Wing orifices		Flap orifices	
Station (percent airfoil chord)	Surface	Station[1] (percent airfoil chord)	Surface
0	Leading edge	75.00	Leading edge
.625	Upper and lower	75.20	Upper and lower
1.25	↓	75.60	↓
2.50		76.40	
5.00		77.50	
7.50		78.80	
10.00		80.00	
15.00		82.50	
20.00		85.00	
25.00		87.00	
30.00		90.00	
35.00		92.50	
40.00		95.00	
45.00		97.50	
50.00		98.80	
55.00			
60.00			
65.00			
70.00			
72.50	Lower		
75.00	Upper and lower		
77.50	Lower		
80.00	Lower		

[1] Flap retracted

TABLE III.– ORDINATES FOR 0.25-CHORD SLOTTED FLAP ON THE NACA 66,2-216 (a = 0.6) AIRFOIL
[Stations and ordinates in percent of airfoil chord]

Station	Upper surface	Lower surface
75.000	–1.875	----
75.521	.042	–3.062
76.042	.895	–3.437
77.083	1.937	–3.504
78.125	2.646	–3.417
79.167	3.125	–3.229
80.208	3.458	–3.042
81.250	3.646	–2.854
82.292	3.687	–2.646
83.333	3.625	–2.437
84.375	3.437	–2.250
85.417	3.208	–2.062
87.500	2.646	–1.667
89.583	2.083	–1.292
91.667	1.542	–.917
93.750	1.062	–.583
95.833	.604	–.333
97.917	.271	–.167
100	----	----
T.E. radius: 0.0625		

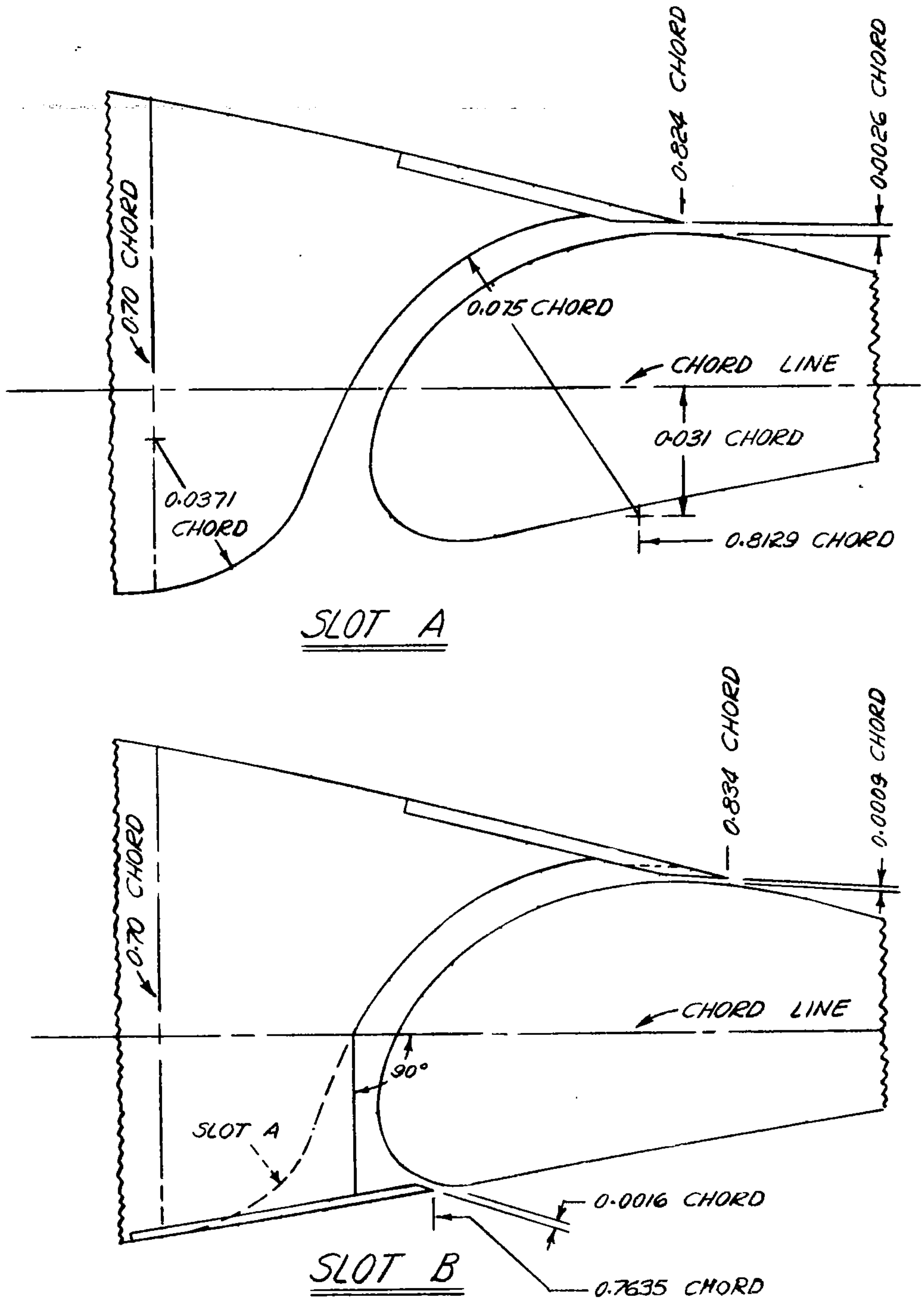

FIGURE 1.- DETAILS OF THE TWO SLOTS TESTED ON THE NACA 66,2-216 (a=0.6) AIRFOIL

(a) Front view (b) Rear view

Figure 2.- The NACA 66,2-216 (a = 0.6) airfoil mounted in the 7- by 10-foot wind tunnel.

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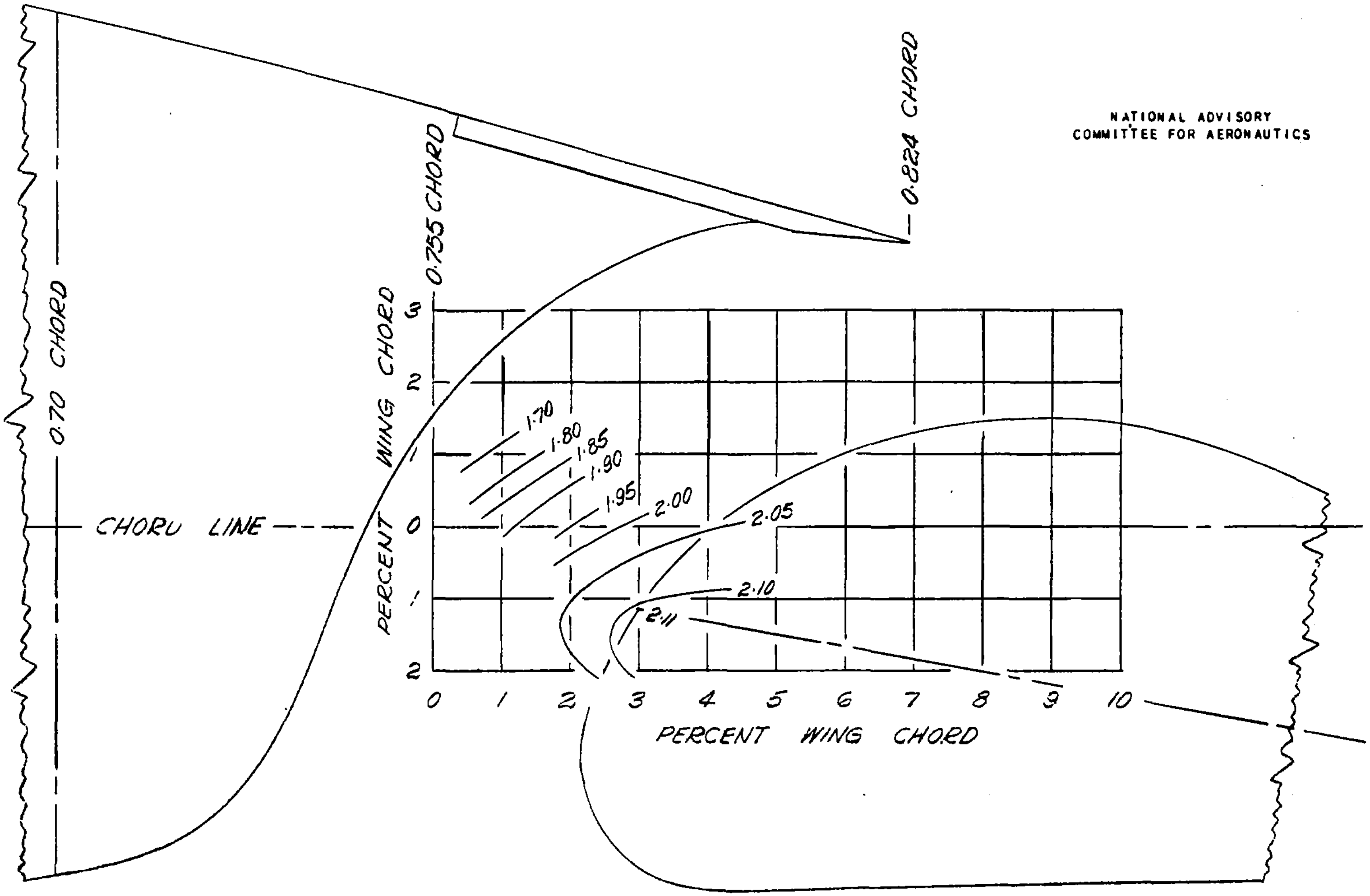
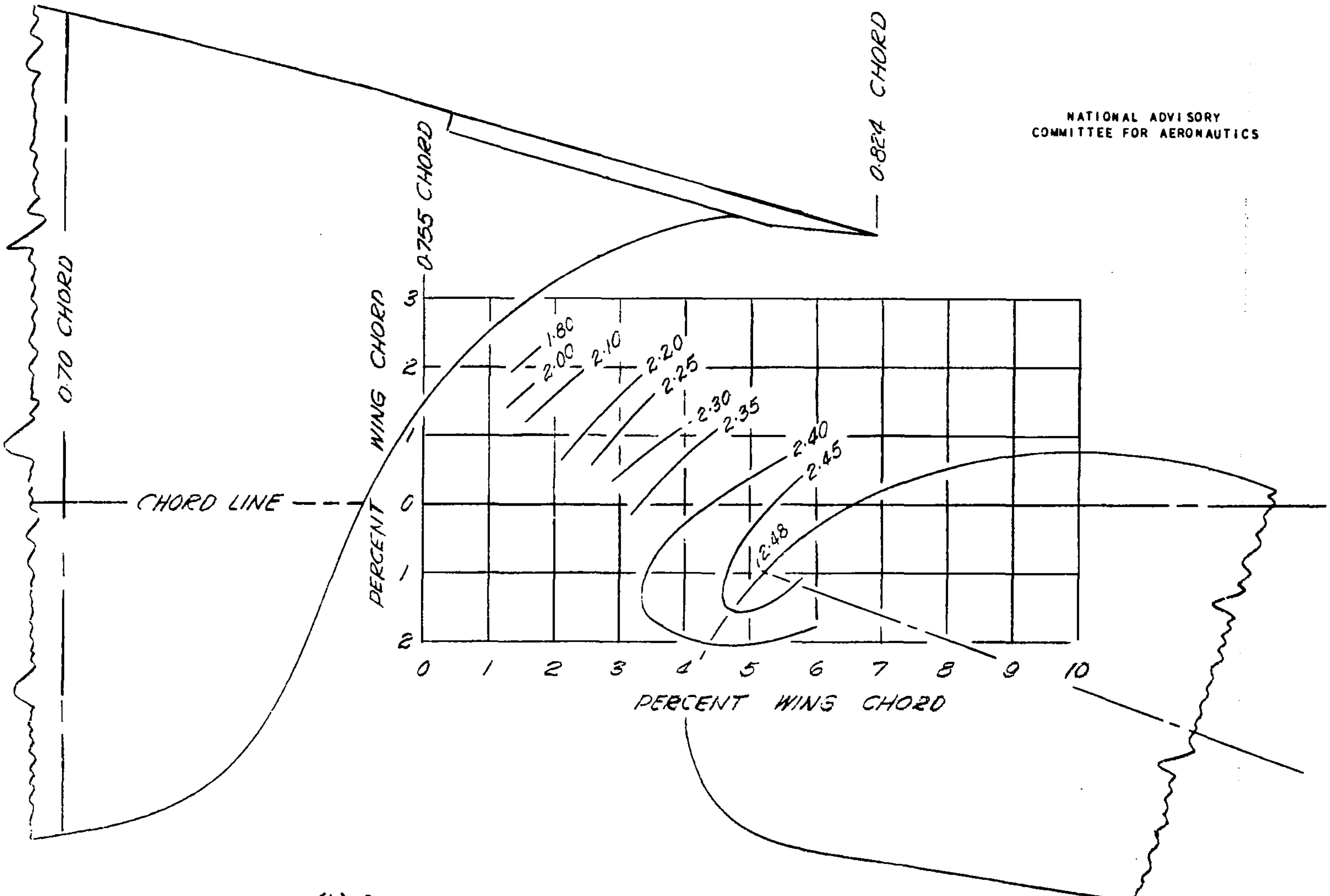


(a) $\delta_f = 10°$

FIGURE 3.- CONTOURS OF FLAP LOCATION FOR MAXIMUM SECTION LIFT COEFFICIENT FOR THE NACA 66,2-216 (a=0.6) AIRFOIL EQUIPPED WITH THE 0.25-CHORD FLAP AND SLOT A



(b) $\delta_f = 20°$

FIGURE 3.- CONTINUED. NACA 66,2-216 (a=0.6) AIRFOIL EQUIPPED WITH THE 0.25-CHORD SLOTTED FLAP.

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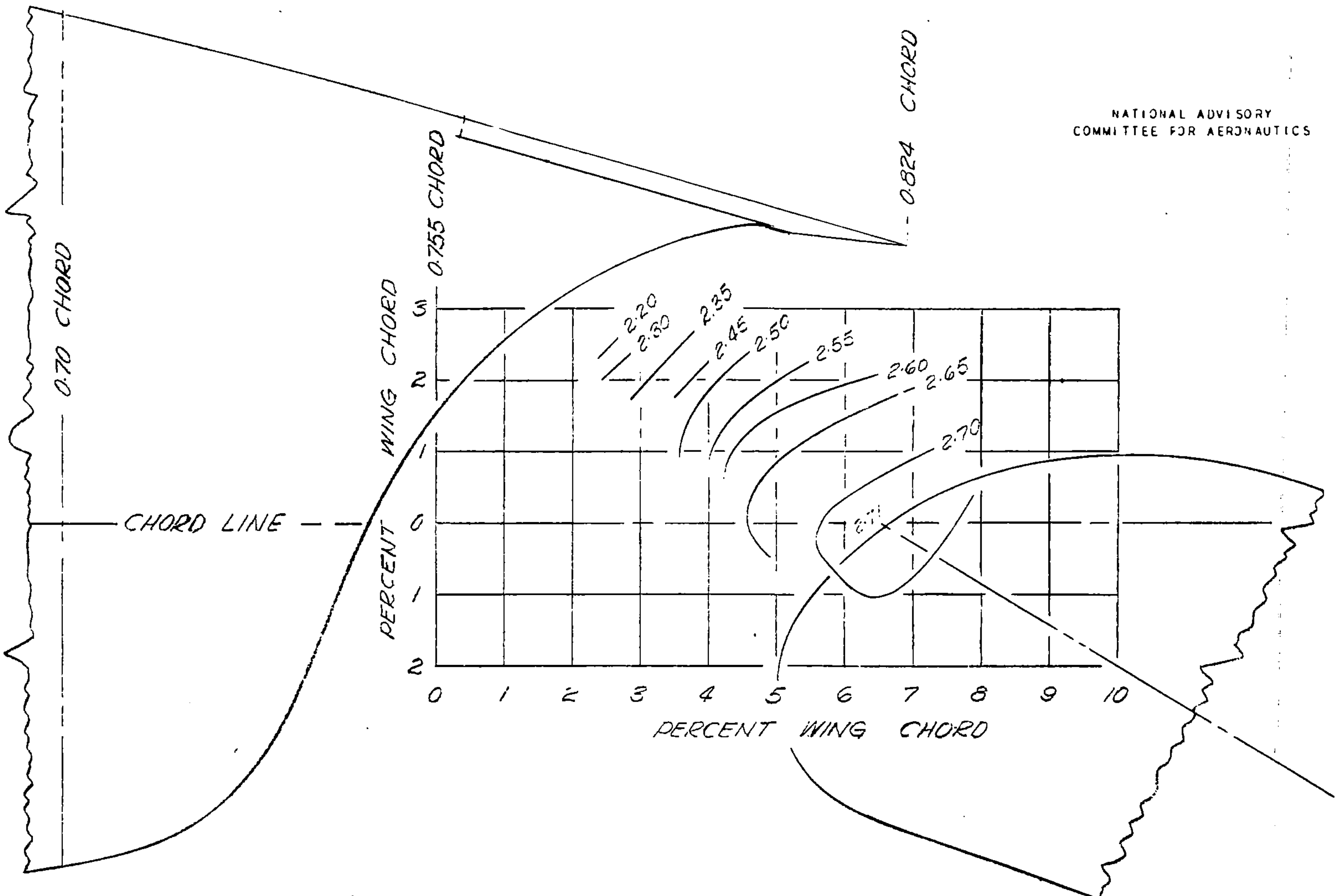
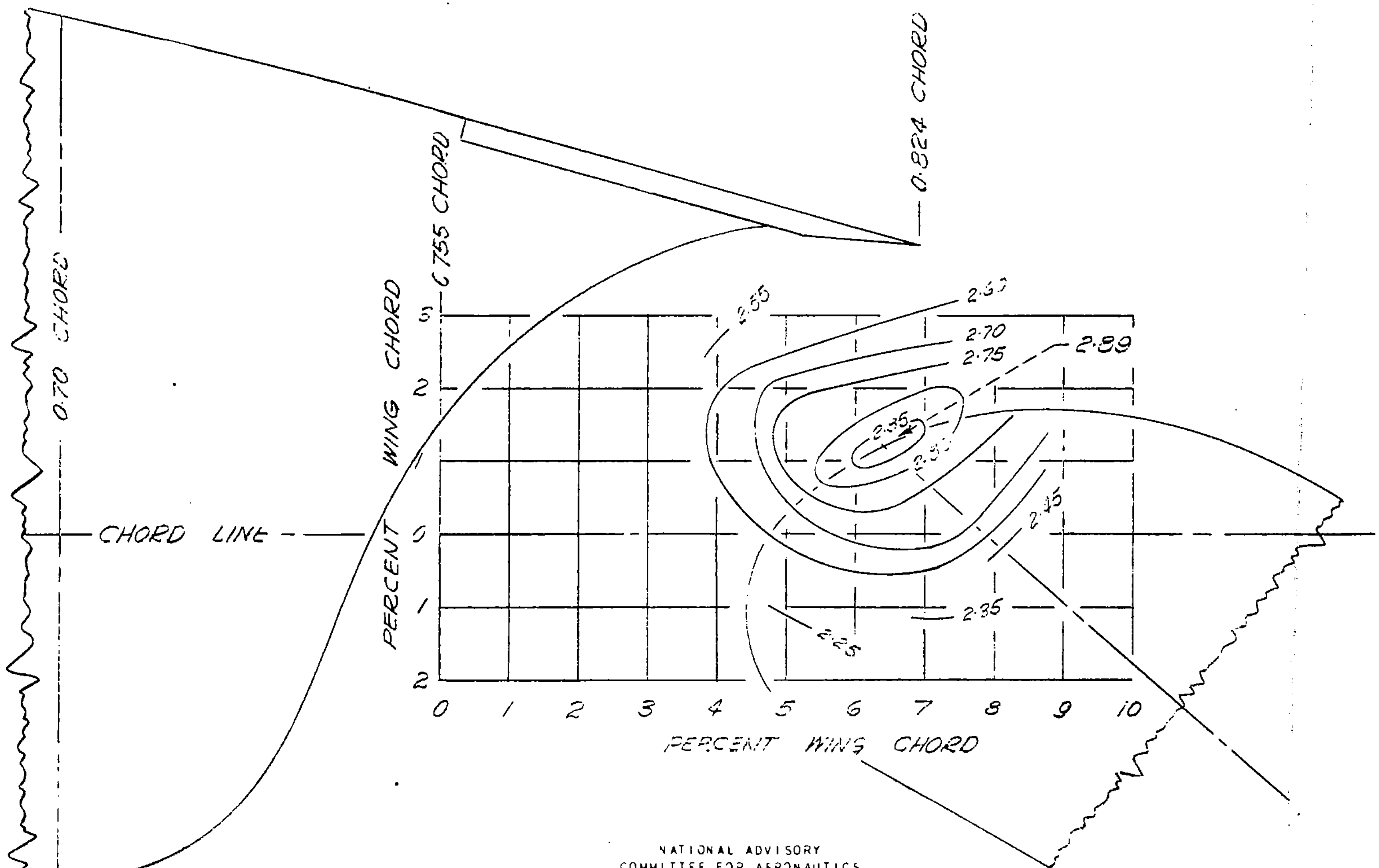


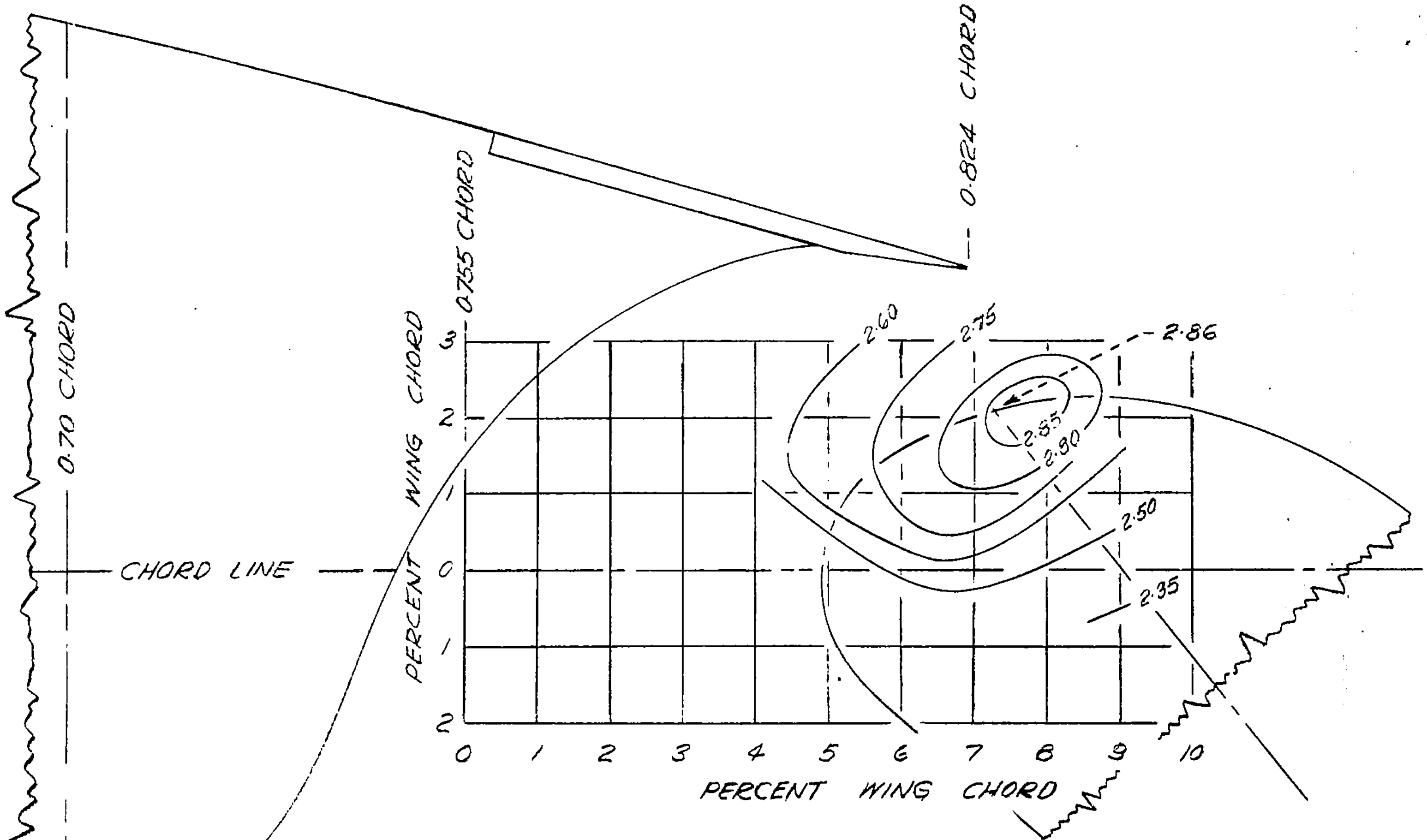
(c.) $\delta_f = 30°$

FIGURE 3- CONTINUED. NACA 66,2-216 (a=0.6) AIRFOIL EQUIPPED WITH THE 0.25-CHORD SLOTTED FLAP



(d) $\delta_f = 40°$

FIGURE 3- CONTINUED. NACA 66,2-216 (a=0.6) AIRFOIL EQUIPPED WITH THE 0.25-CHORD SLOTTED FLAP.



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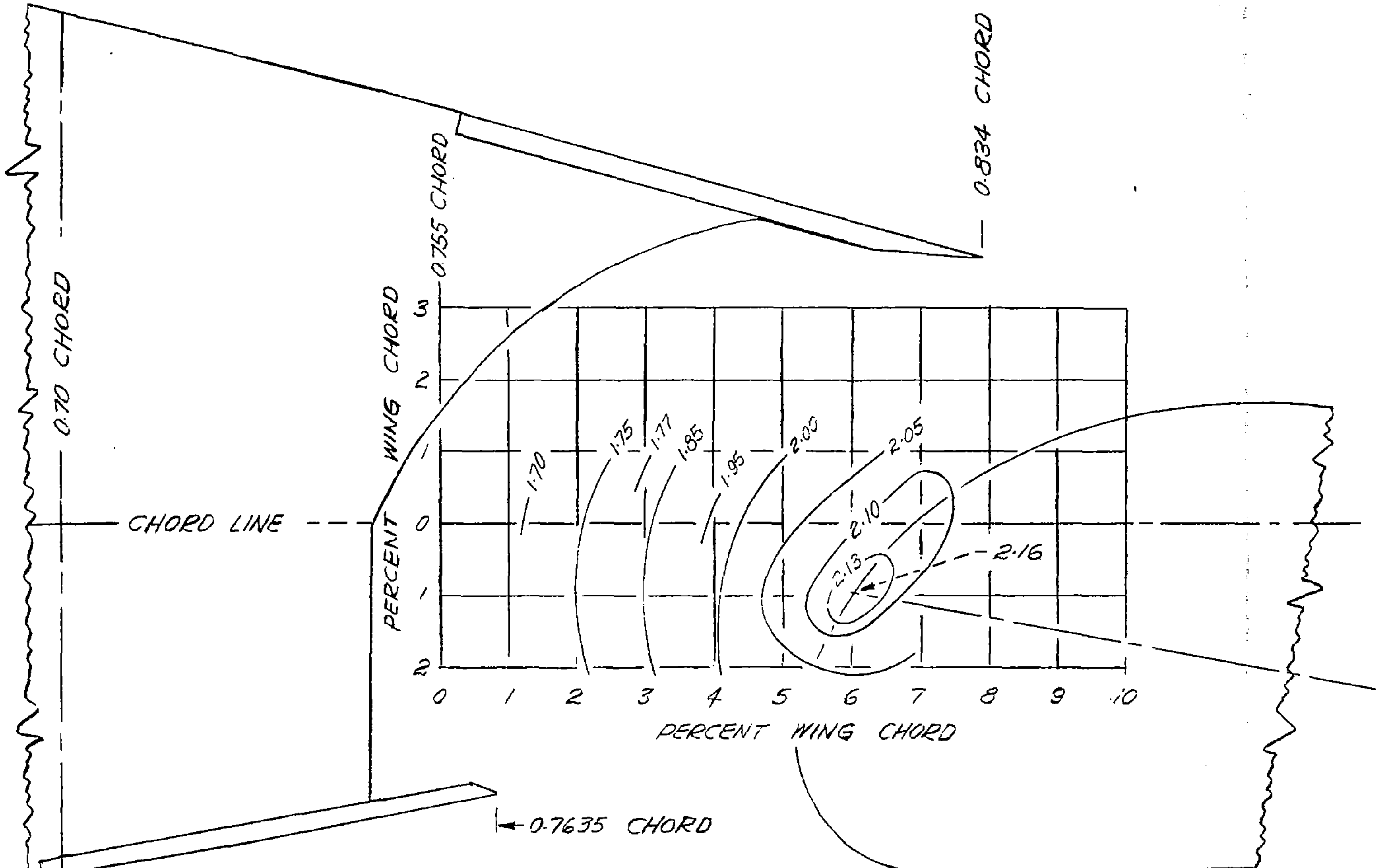
(e.) $\delta_f = 50°$

FIGURE 3.- CONCLUDED. NACA 66,2-216 (a=0.6) AIRFOIL EQUIPPED WITH THE 0.25-CHORD SLOTTED FLAP.



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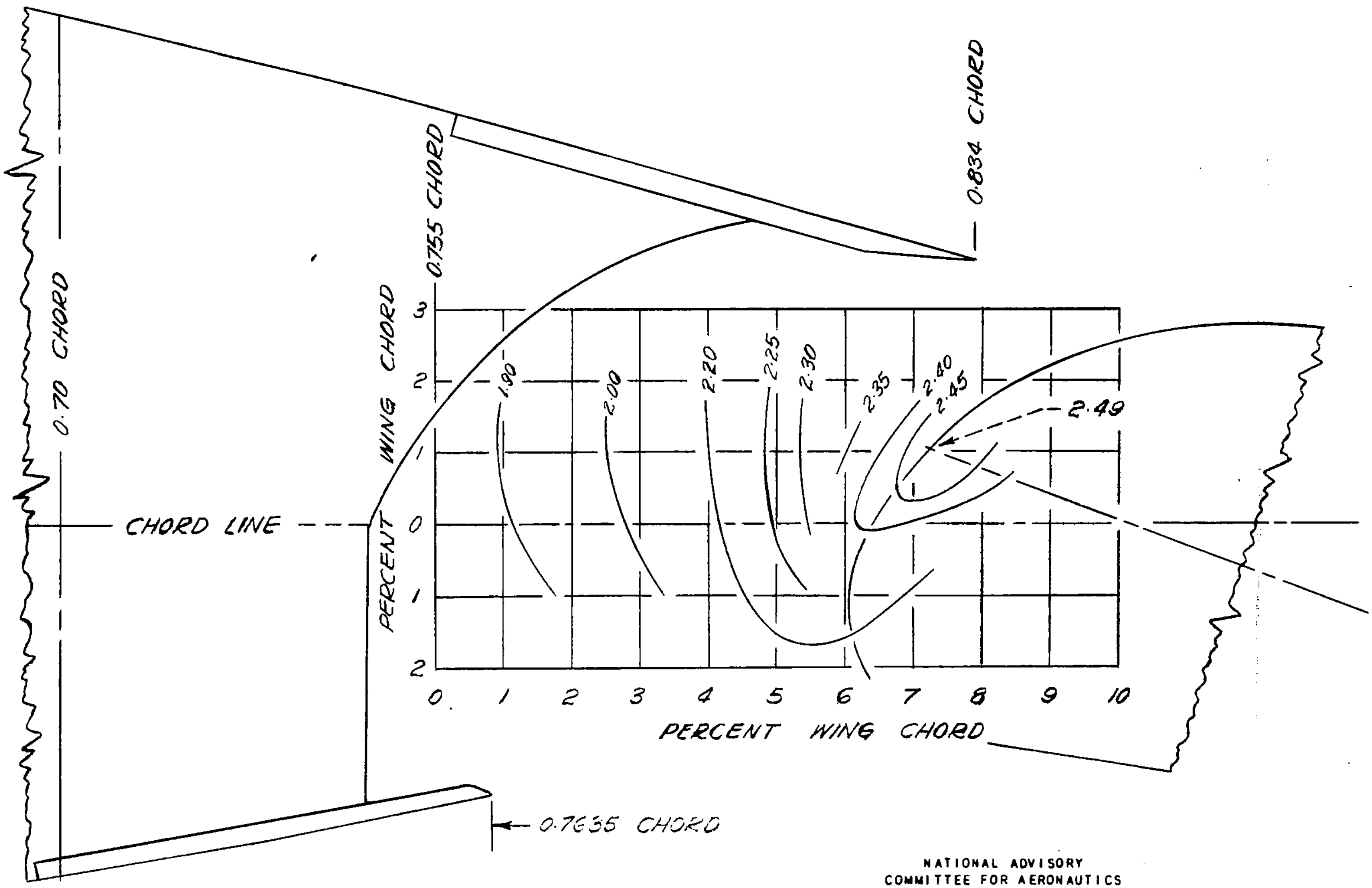
(a) $\delta_f = 10°$

FIGURE 4.- CONTOURS OF FLAP LOCATION FOR MAXIMUM SECTION LIFT COEFFICIENT FOR THE NACA 66,2-216 (a=0.6) AIRFOIL EQUIPPED WITH THE 0.25-CHORD FLAP AND SLOT B



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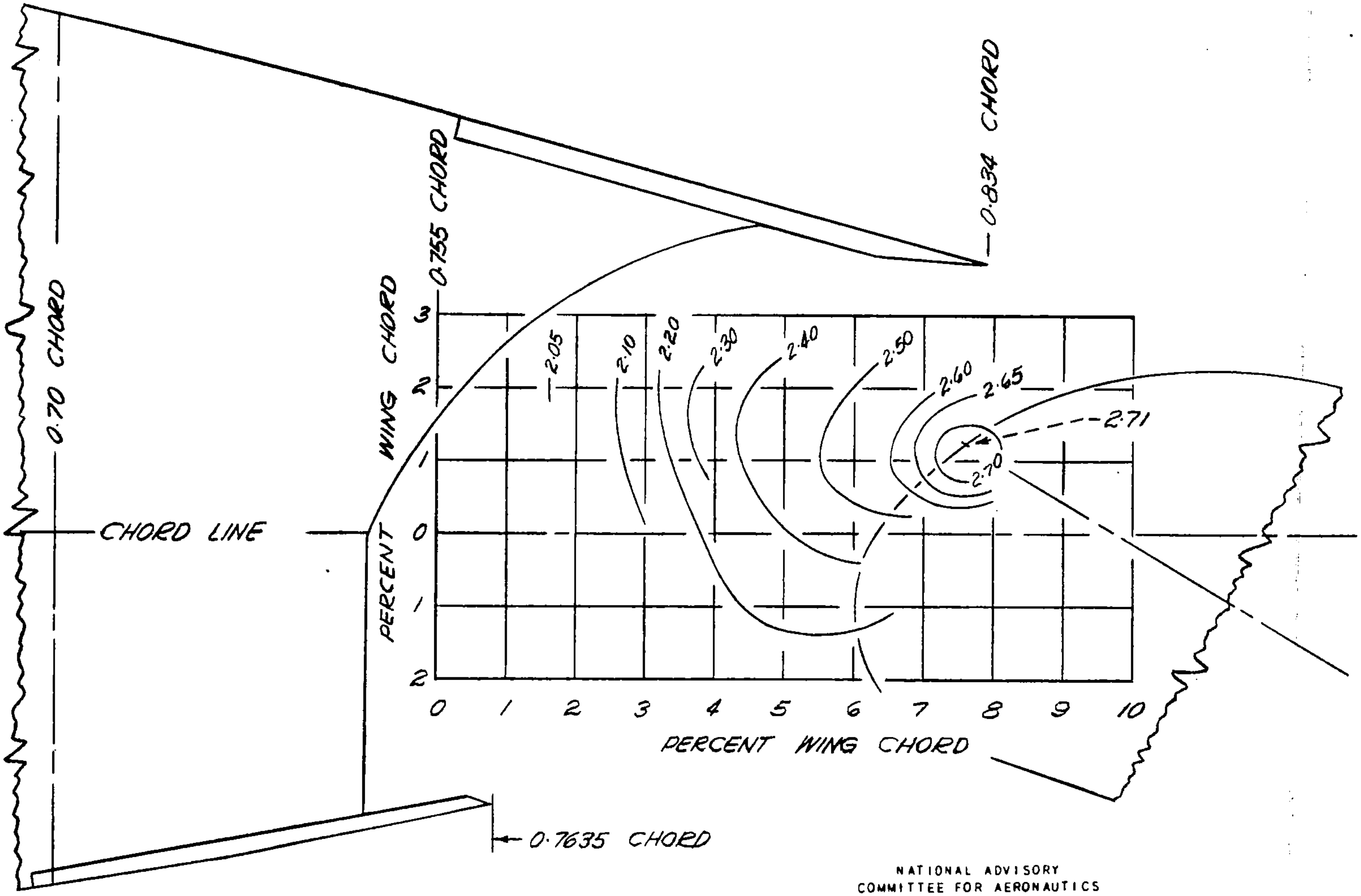
(b.) $\delta_f = 20°$

FIGURE 4.- CONTINUED. NACA 66,2-216 (a=0.6) AIRFOIL EQUIPPED WITH THE 0.25-CHORD SLOTTED FLAP.



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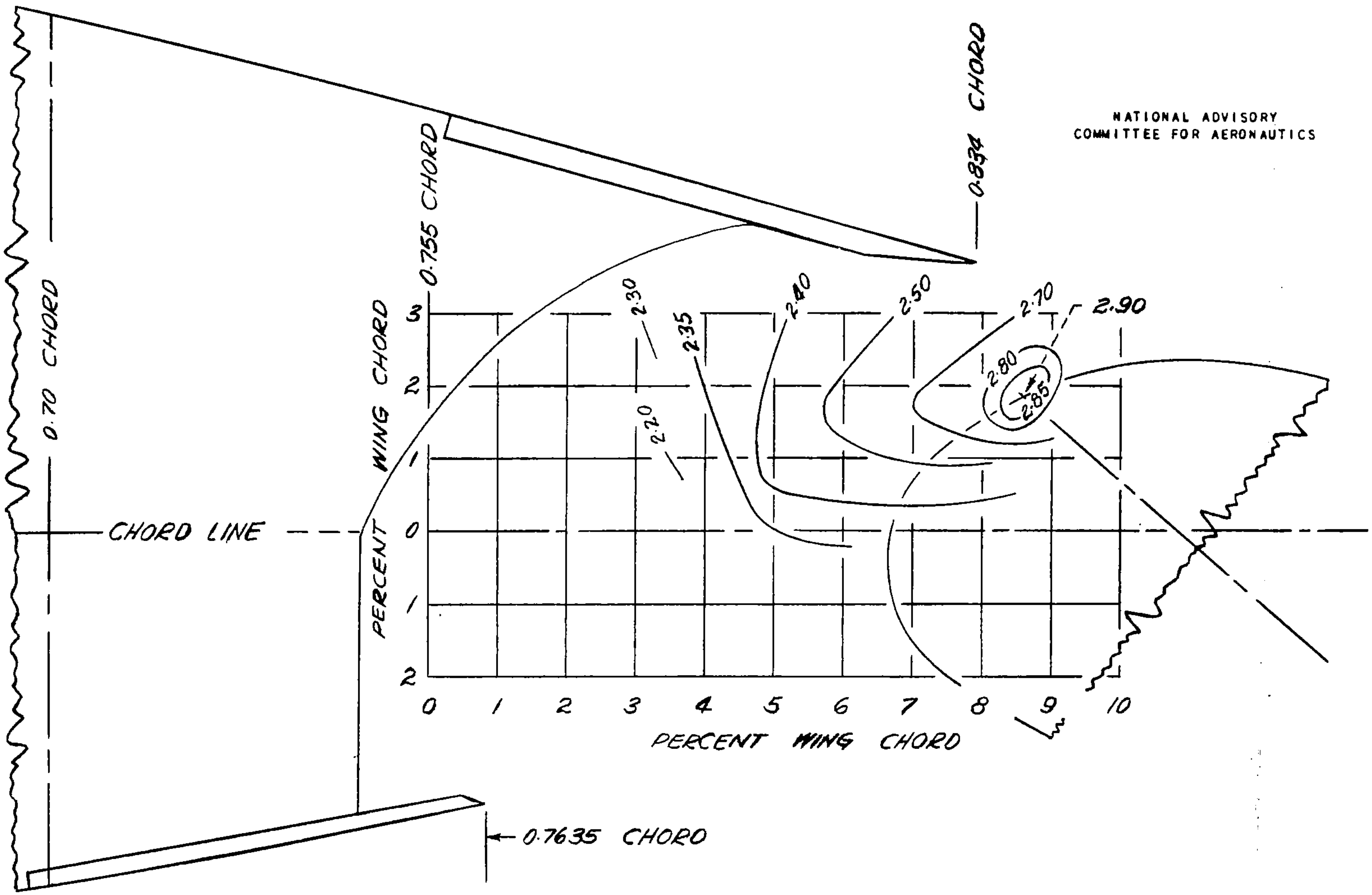
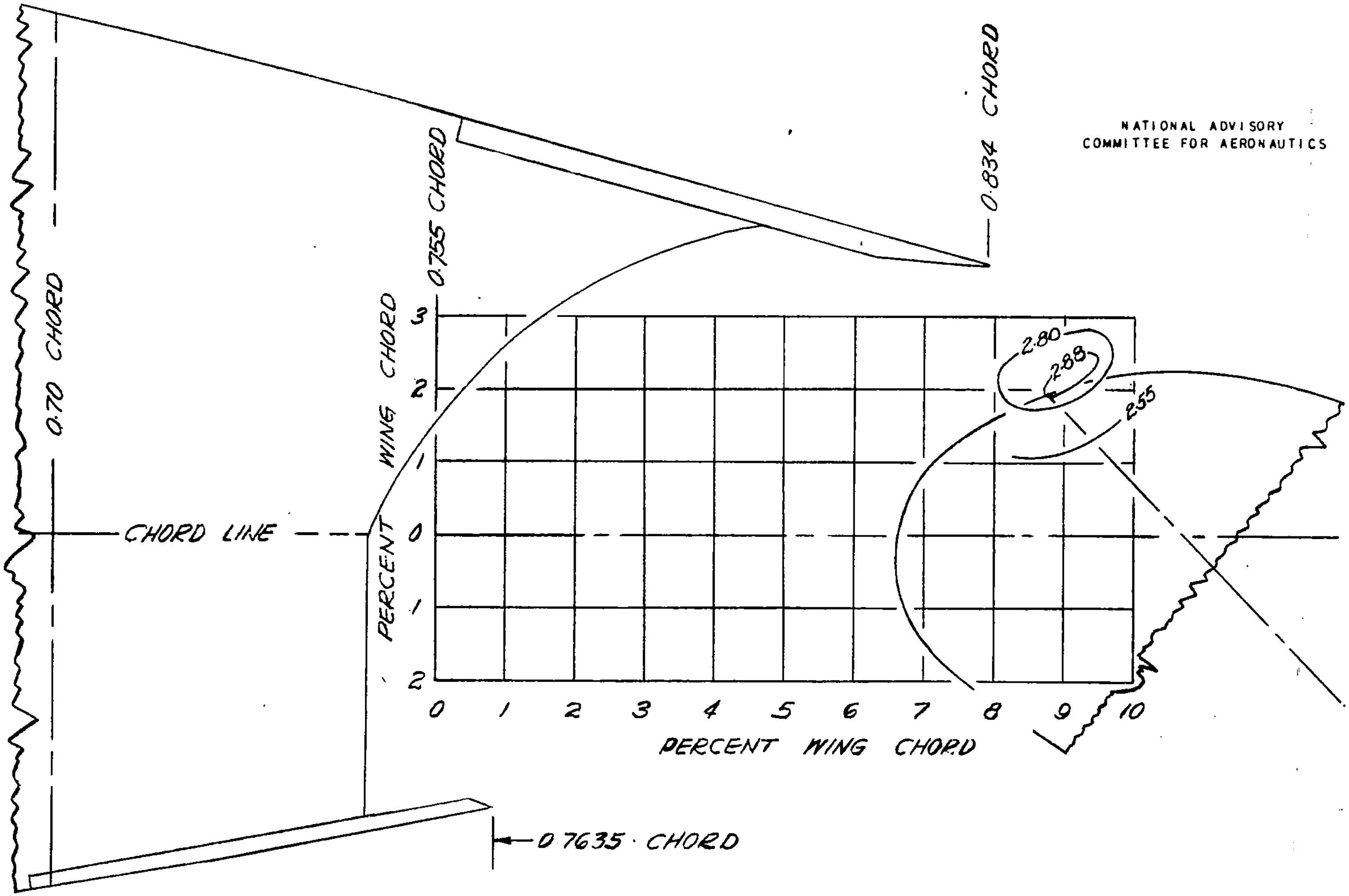
(c.) $\delta_f = 30°$

FIGURE 4- CONTINUED. NACA 66,2-216 (a=0.6) AIRFOIL EQUIPPED WITH THE 0.25-CHORD SLOTTED FLAP.



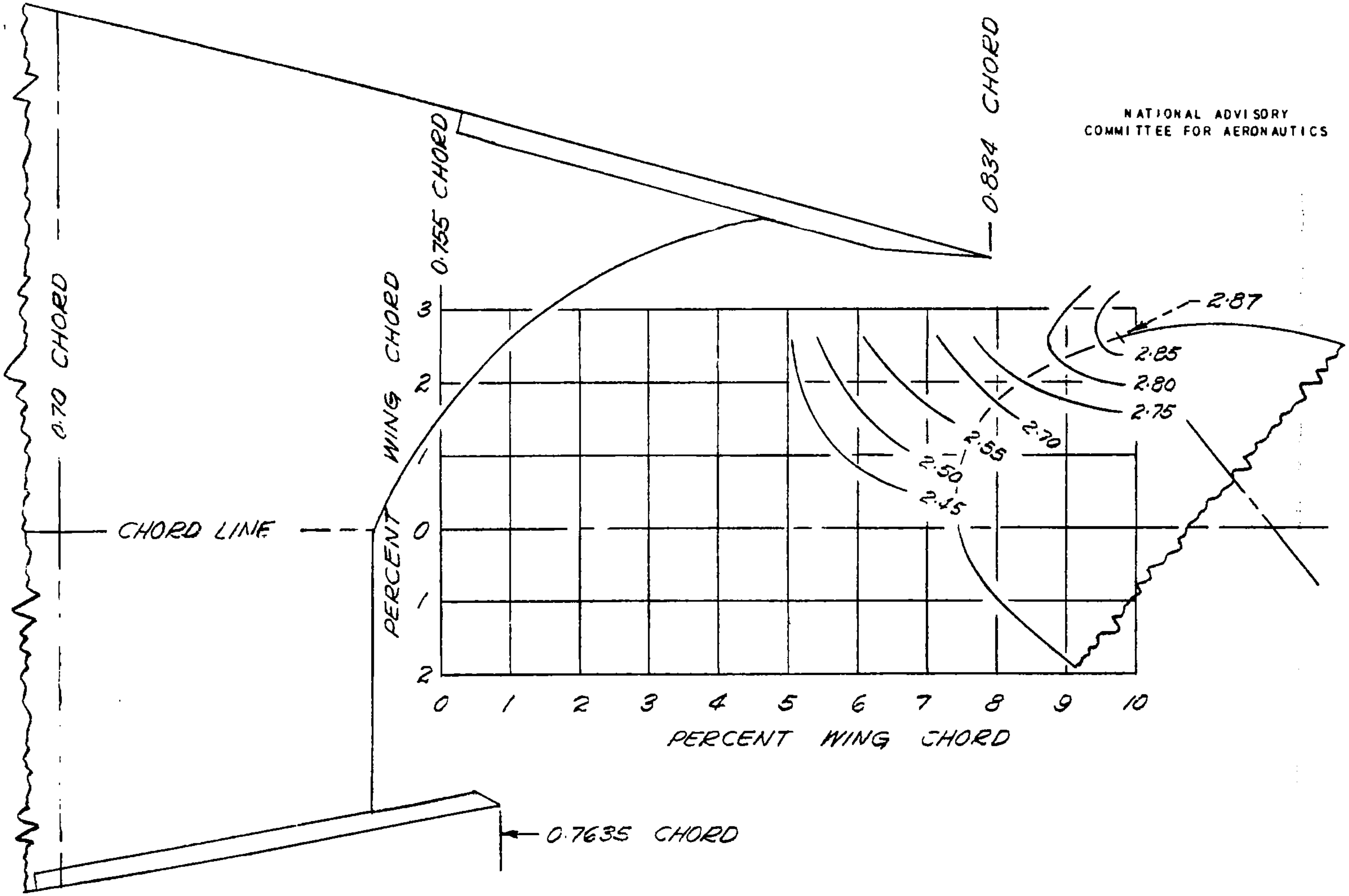
(d) $\delta_f = 40°$

FIGURE 4- CONTINUED. NACA 66,2-216 (a=0.6) AIRFOIL EQUIPPED WITH THE 0.25-CHORD SLOTTED FLAP.



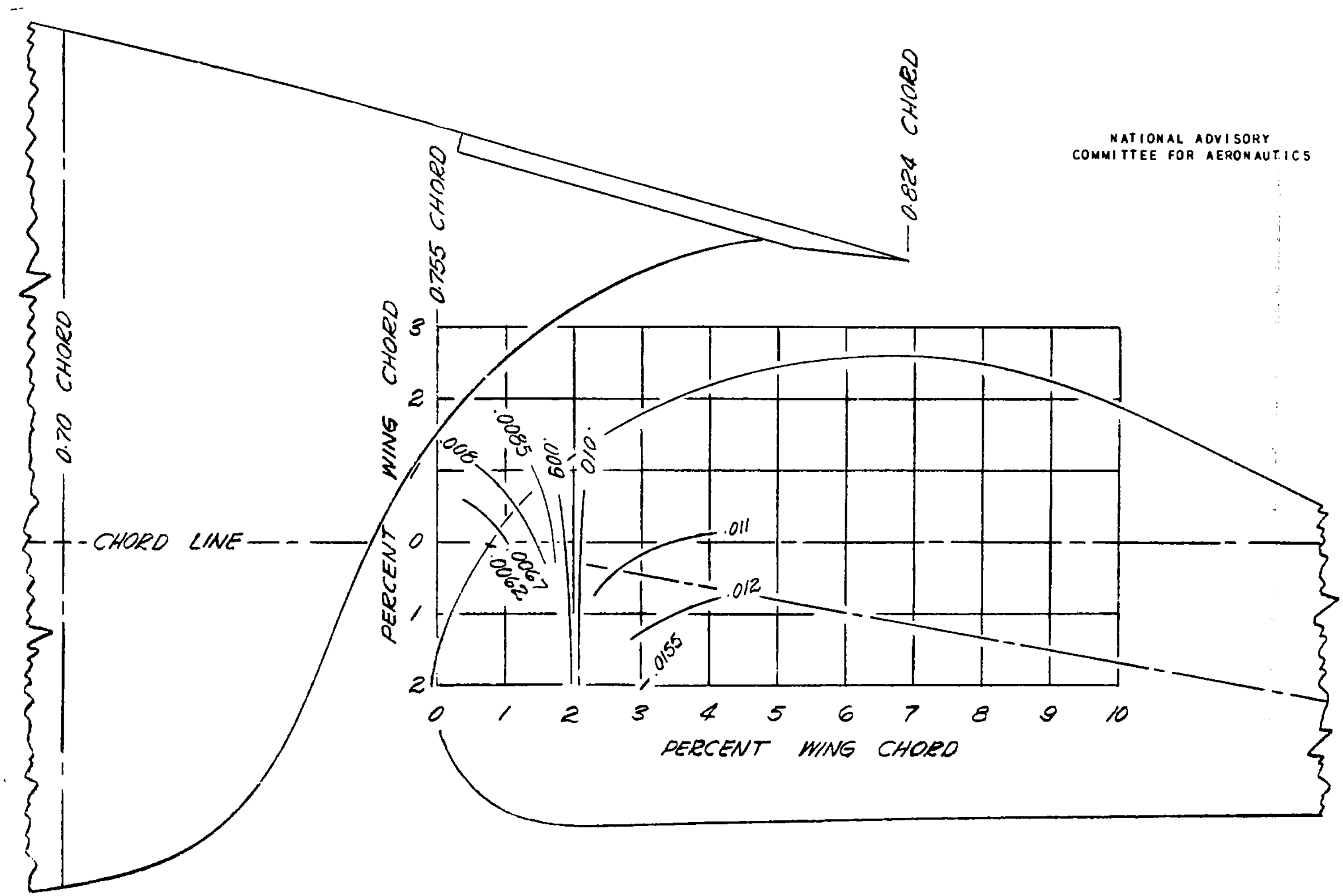
(e.) $\delta_f = 45°$

FIGURE 4.- CONTINUED. NACA 66,2-216 (a=0.6) AIRFOIL EQUIPPED WITH THE 0.25-CHORD SLOTTED FLAP.



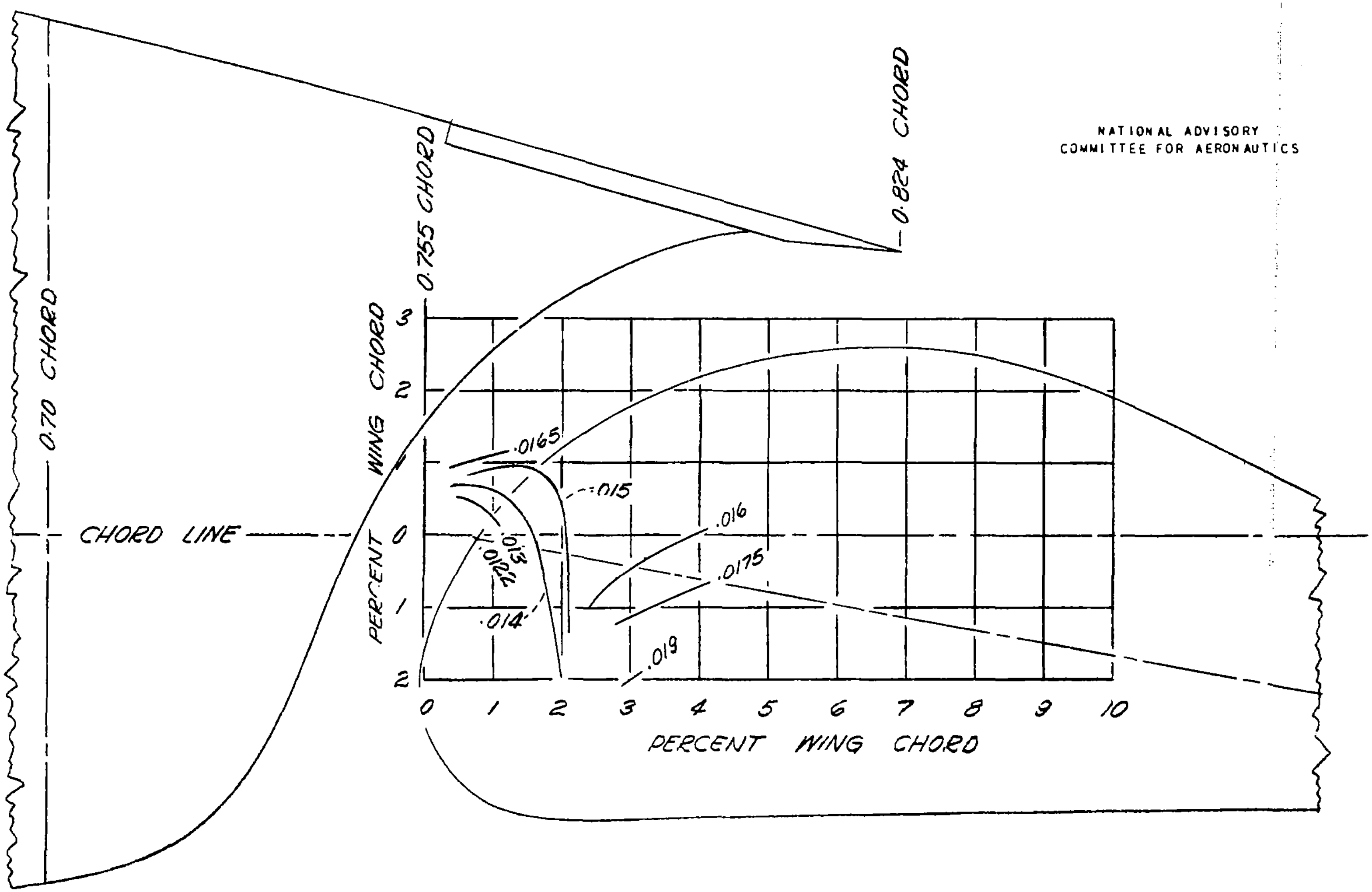
(f.) $\delta_f = 50°$

FIGURE 4.- CONCLUDED. NACA 66,2-216 (a=0.6) AIRFOIL EQUIPPED WITH THE 0.25-CHORD SLOTTED FLAP.



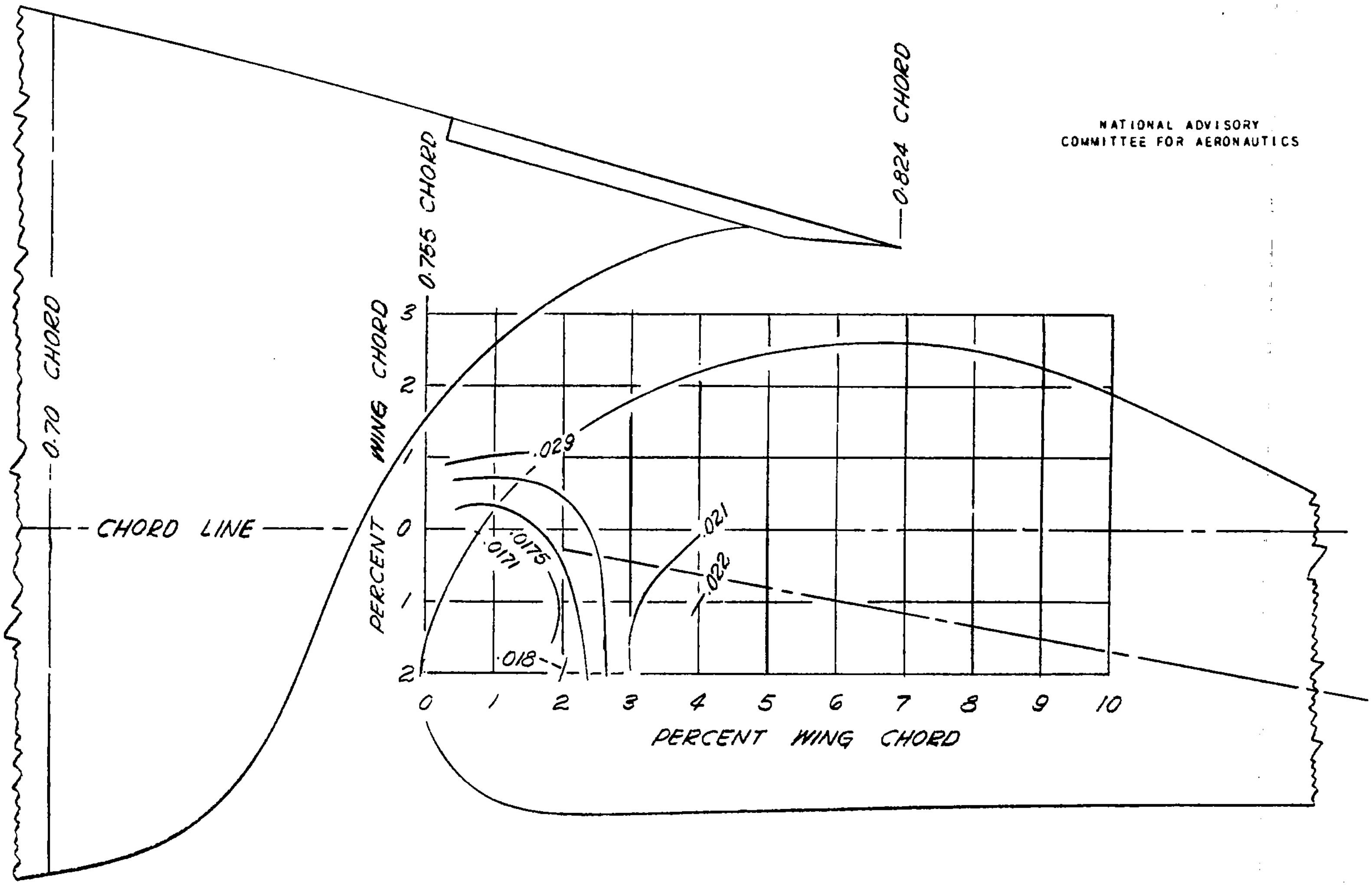
(a.) $\delta_f = 10°$, $c_l = 0.6$

FIGURE 5- CONTOURS OF FLAP LOCATION FOR MINIMUM PROFILE-DRAG COEFFICIENT FOR THE NACA 66,2-216 (a=0.6) AIRFOIL EQUIPPED WITH THE 0.25-CHORD FLAP AND SLOT A



(b.) $\delta_f = 10°$, $c_l = 1.0$

FIGURE 5- CONTINUED. NACA 66,2-216 (a=0.6) AIRFOIL EQUIPPED WITH THE 0.25-CHORD SLOTTED FLAP.



(c) $\delta_f = 10°$, $c_l = 1.5$

FIGURE 5.- CONTINUED. NACA 66,2-216 (a=0.6) AIRFOIL EQUIPPED WITH THE 0.25-CHORD SLOTTED FLAP.

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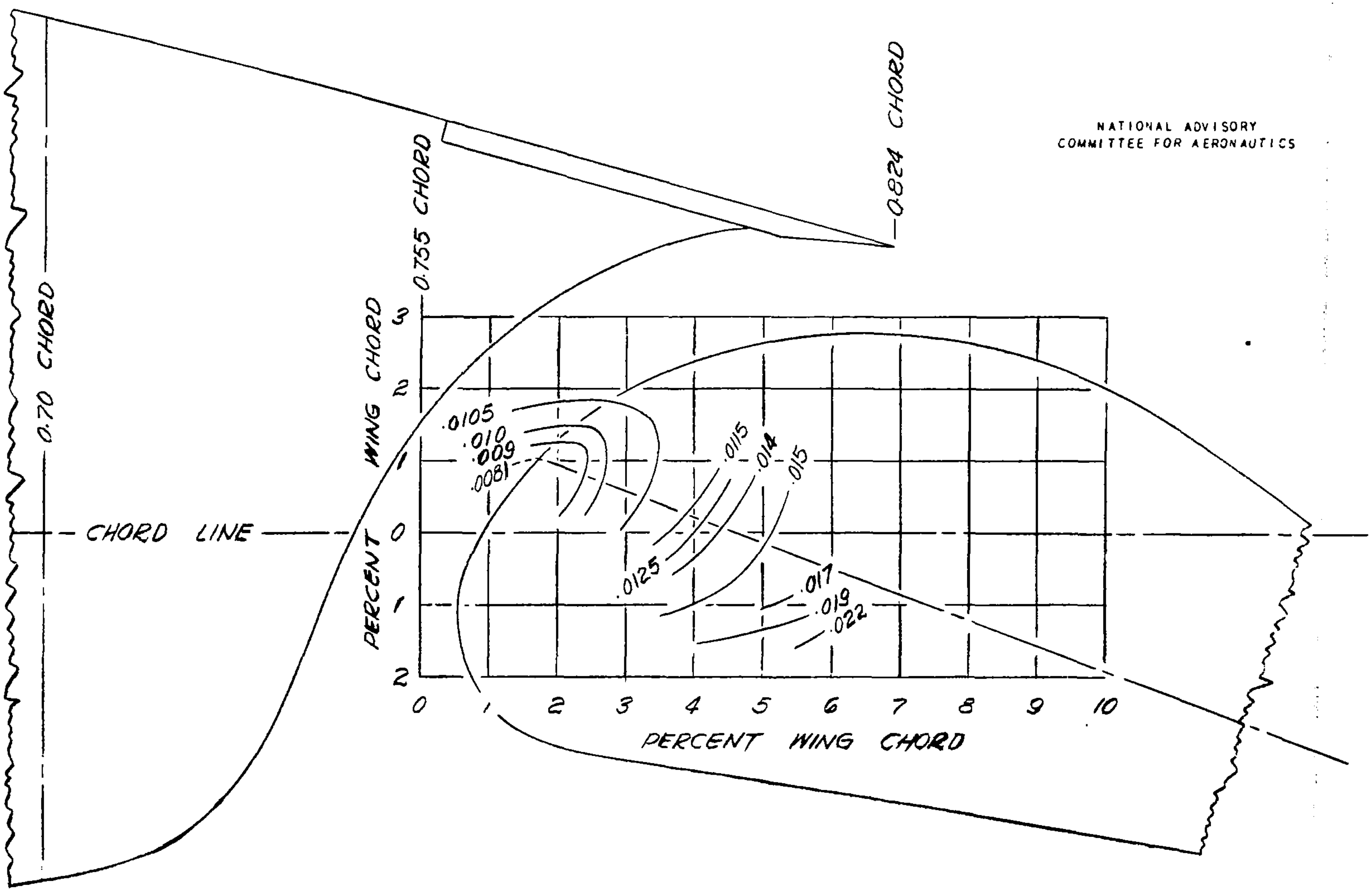

(d) $\delta_f = 20°$, $c_l = 1.0$

FIGURE 5.- CONTINUED. NACA 66,2-216 (a=0.6) AIRFOIL EQUIPPED WITH THE 0.25-CHORD SLOTTED FLAP.

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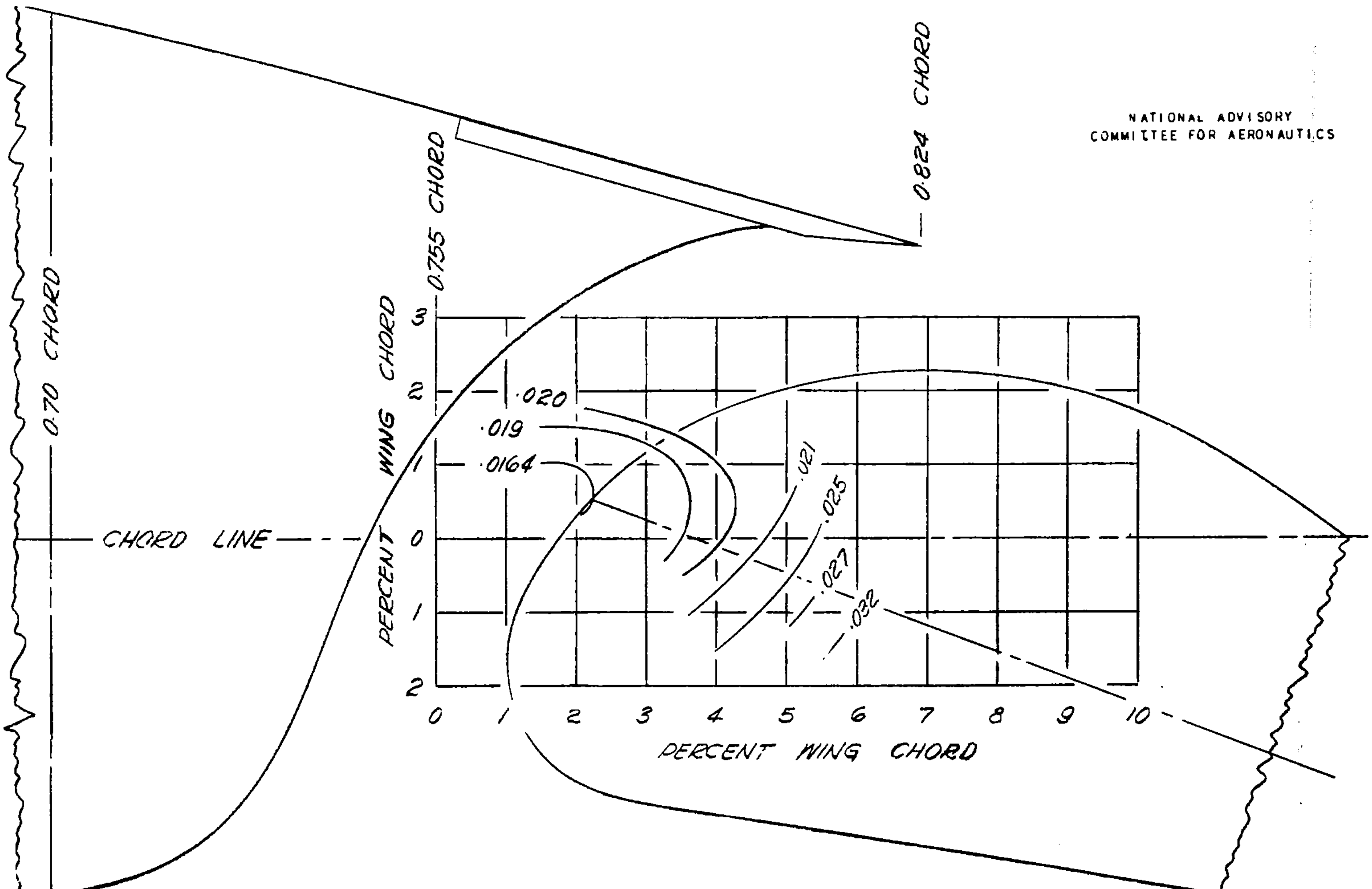

(e.) $\delta_f = 20°$, $c_l = 1.5$

FIGURE 5- CONTINUED. NACA 66,2-216 (a=0.6) AIRFOIL EQUIPPED WITH THE 0.25-CHORD SLOTTED FLAP.

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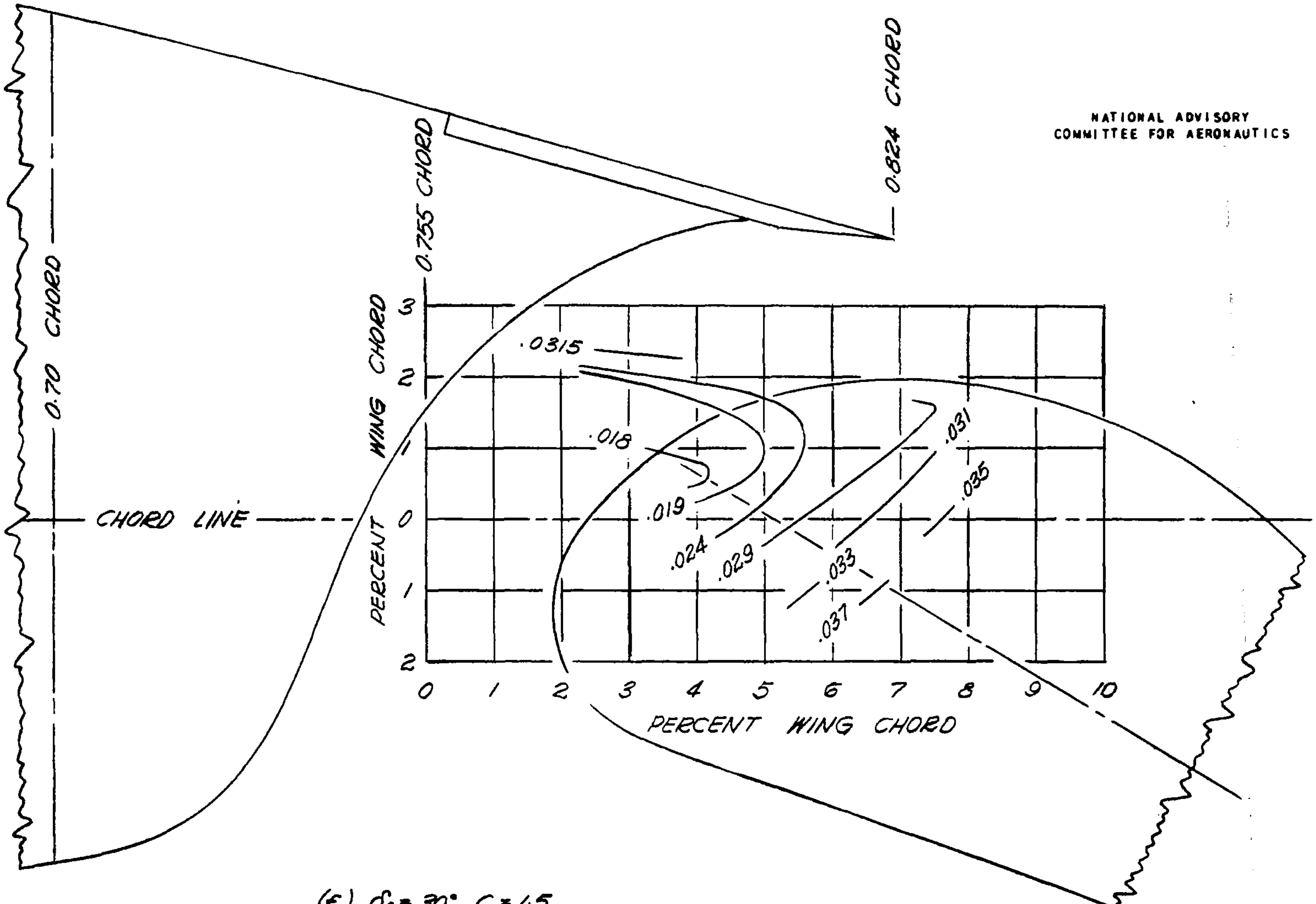
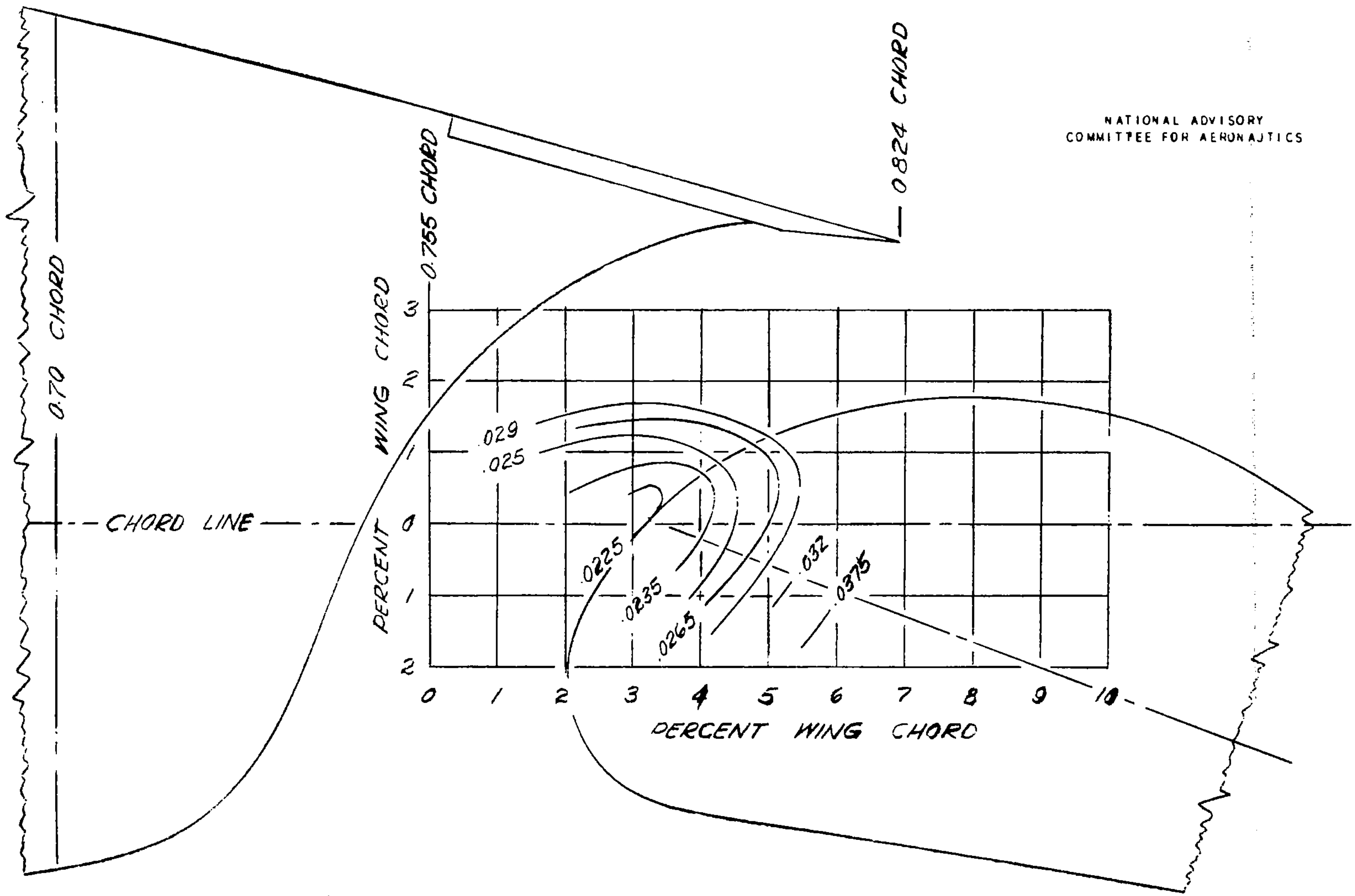


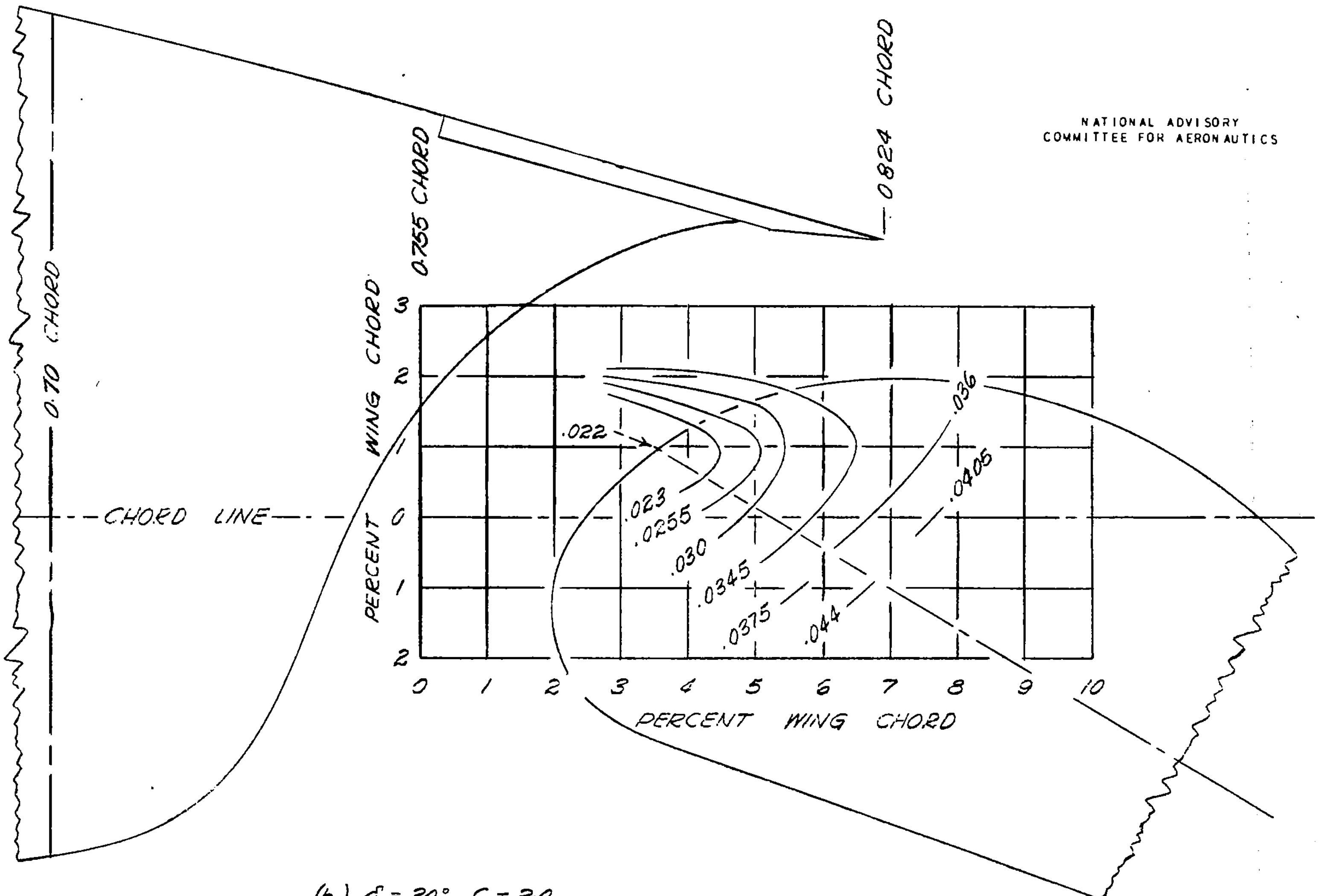
(f.) $\delta_f = 30^\circ$, $c_l = 1.5$

FIGURE 5.- CONTINUED. NACA 66,2-216 (a=0.6) AIRFOIL EQUIPPED WITH THE 0.25-CHORD SLOTTED FLAP.



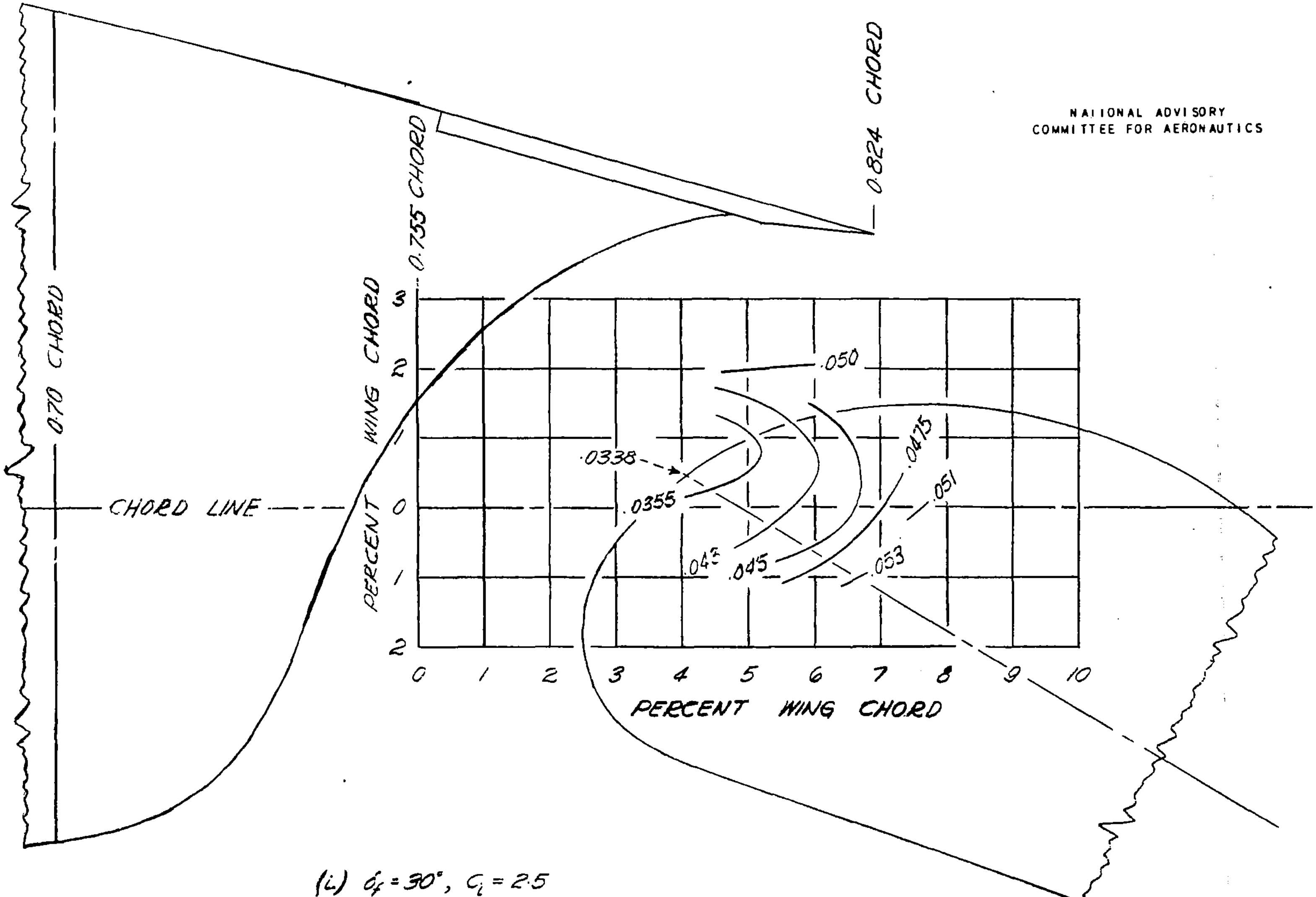
(g.) $\delta_f = 20°$, $c_l = 2.0$

FIGURE 5.- CONTINUED. NACA 66,2-216 (a=0.6) AIRFOIL EQUIPPED WITH THE 0.25-CHORD SLOTTED FLAP.



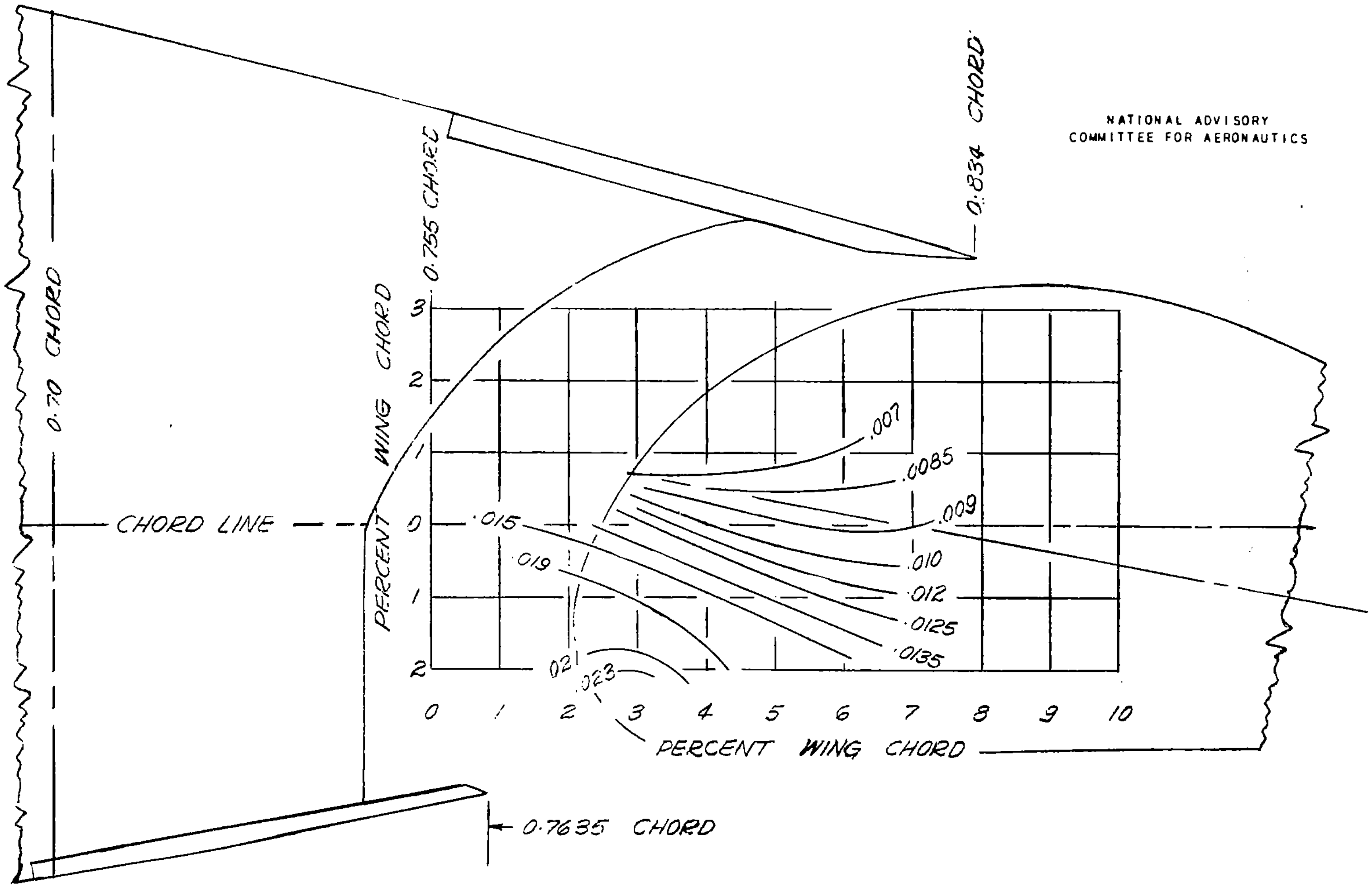
(h.) $\delta_f = 30°$, $G = 2.0$

FIGURE 5.- CONTINUED. NACA 66,2-216 (a=0.6) AIRFOIL EQUIPPED WITH THE 0.25 CHORD SLOTTED FLAP.



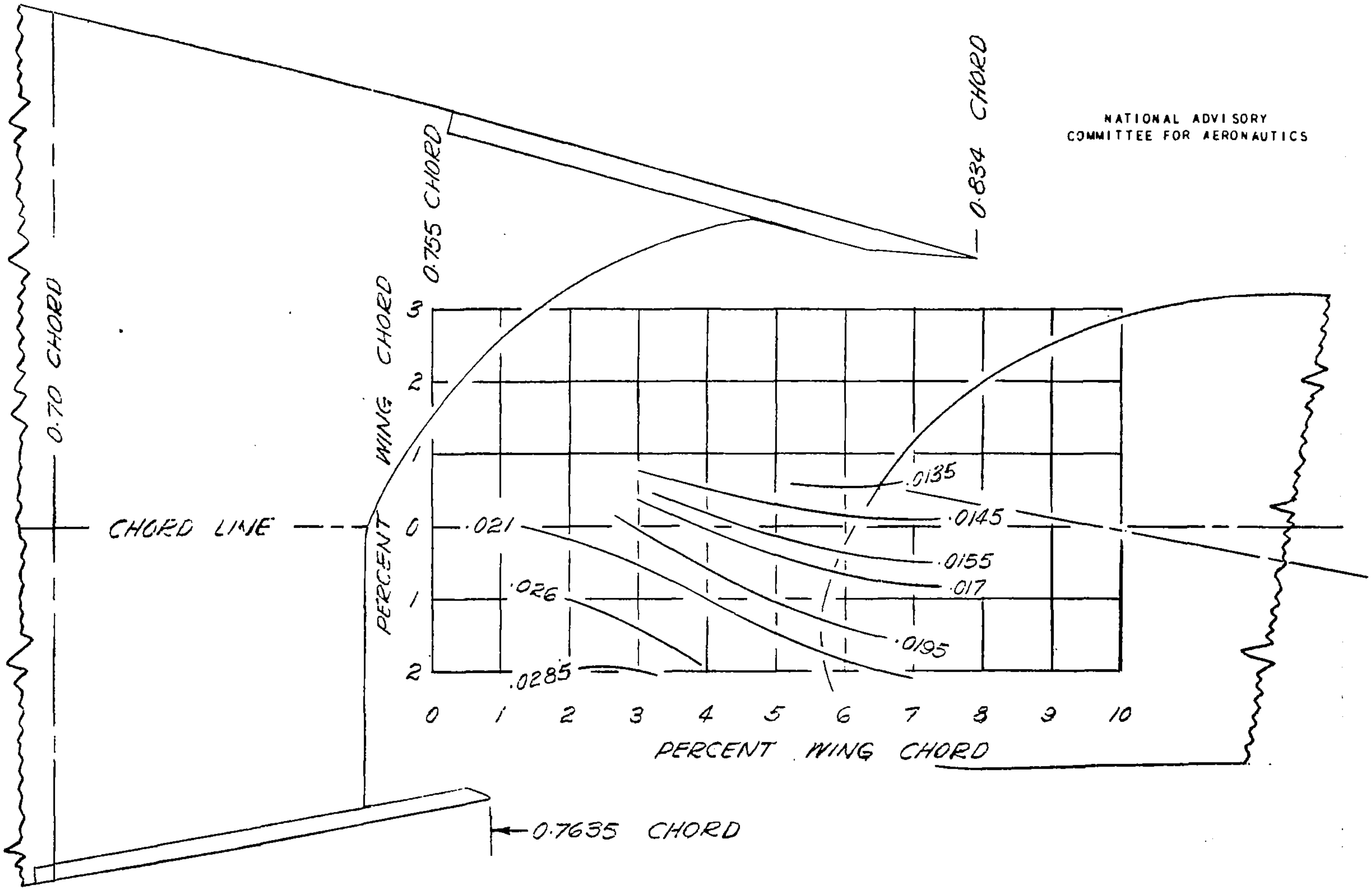
(i) $\delta_f = 30°$, $c_l = 2.5$

FIGURE 5.- CONCLUDED. NACA 66,2-216 (a=0.6) AIRFOIL EQUIPPED WITH THE 0.25-CHORD SLOTTED FLAP.



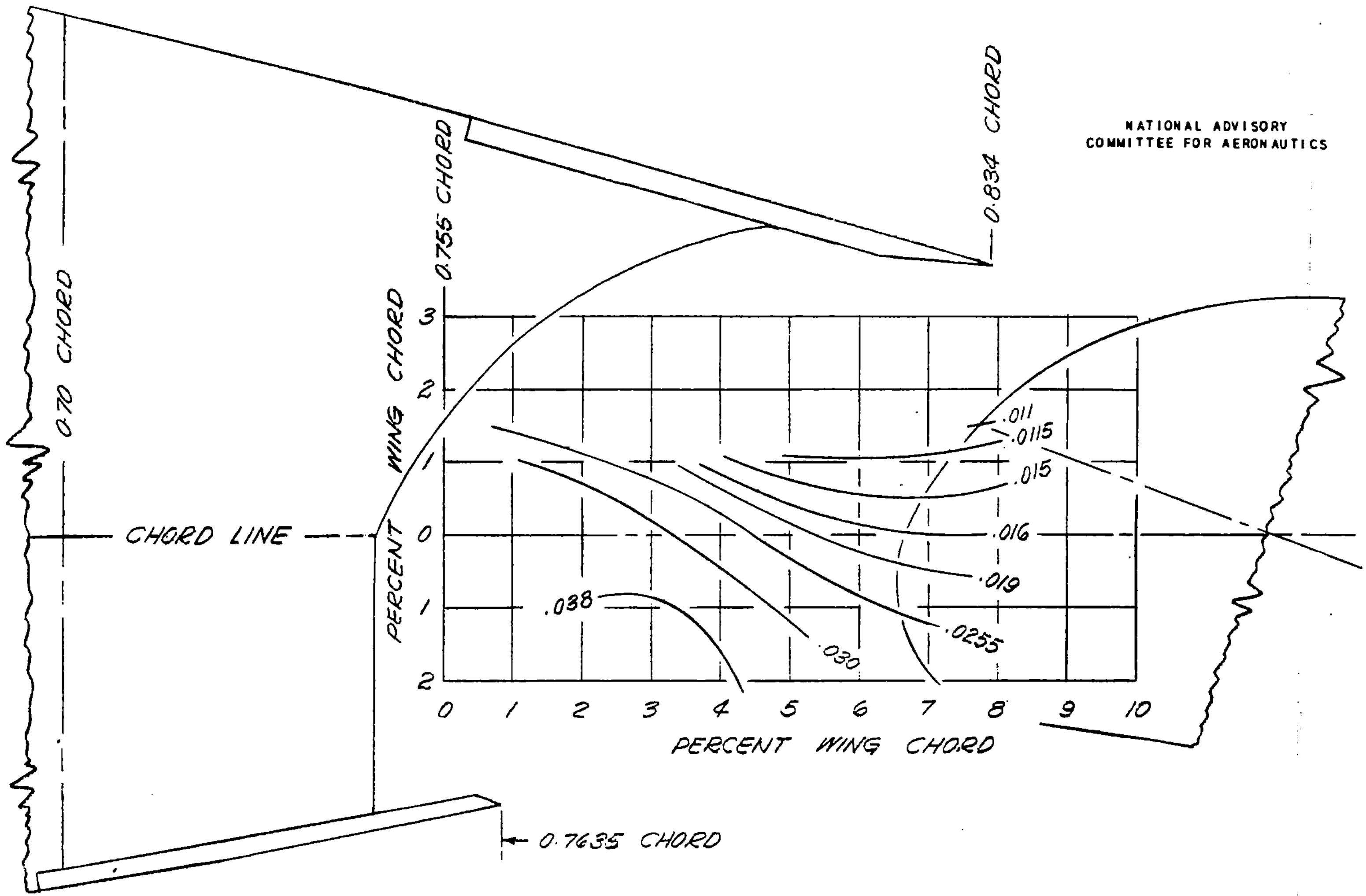
(a.) $\delta_f = 10°$, $c_l = 0.6$

FIGURE 6.- CONTOURS OF FLAP LOCATION FOR MINIMUM PROFILE-DRAG COEFFICIENT FOR THE NACA 66,2-216 (a=0.6) AIRFOIL EQUIPPED WITH THE 0.25-CHORD FLAP AND SLOT B



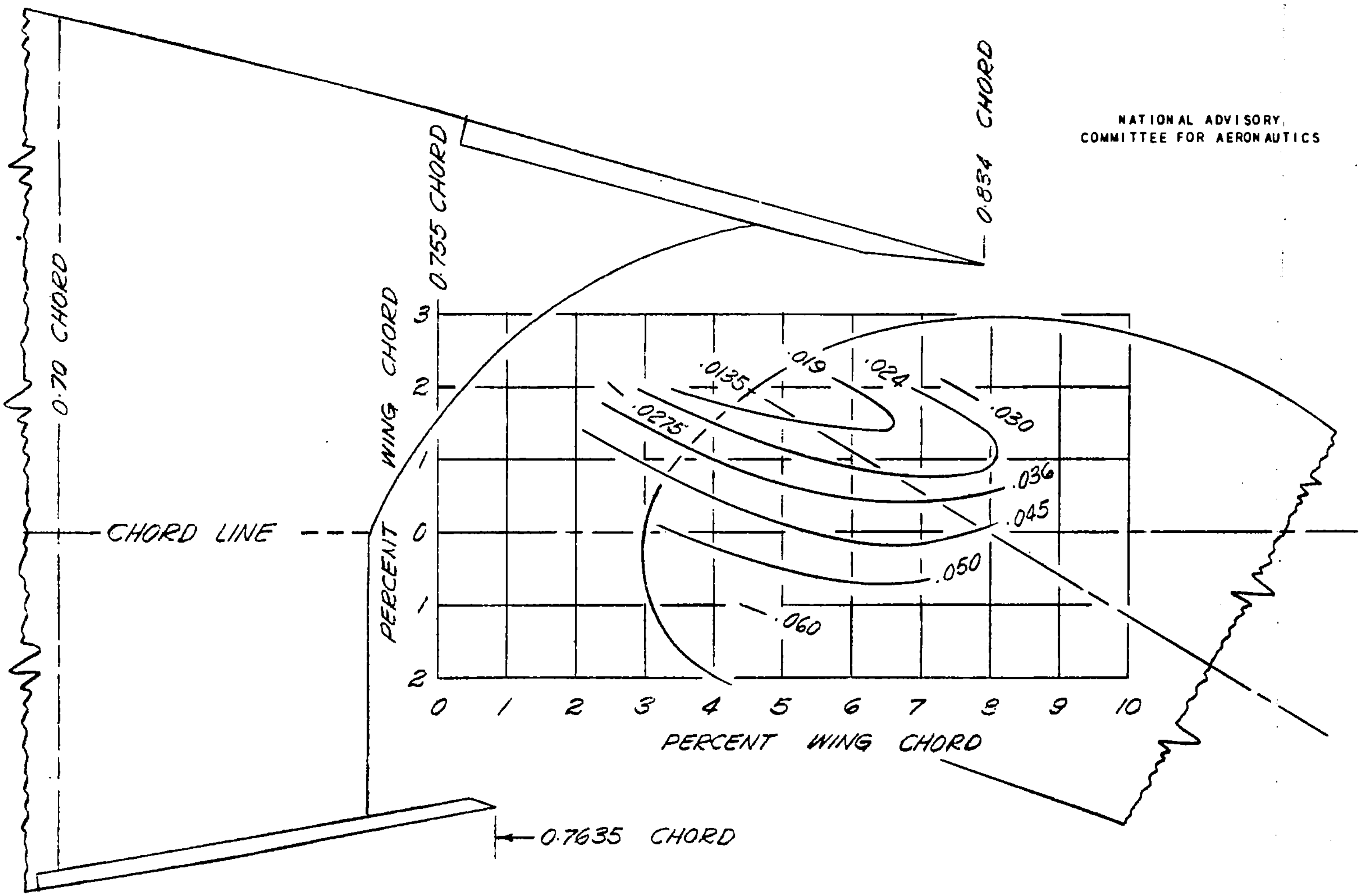
(c.) $\delta_f = 10°$, $c_l = 1.0$

FIGURE 6.- CONTINUED. NACA 66,2-216 (a=0.6) AIRFOIL EQUIPPED WITH THE 0.25-CHORD SLOTTED FLAP.



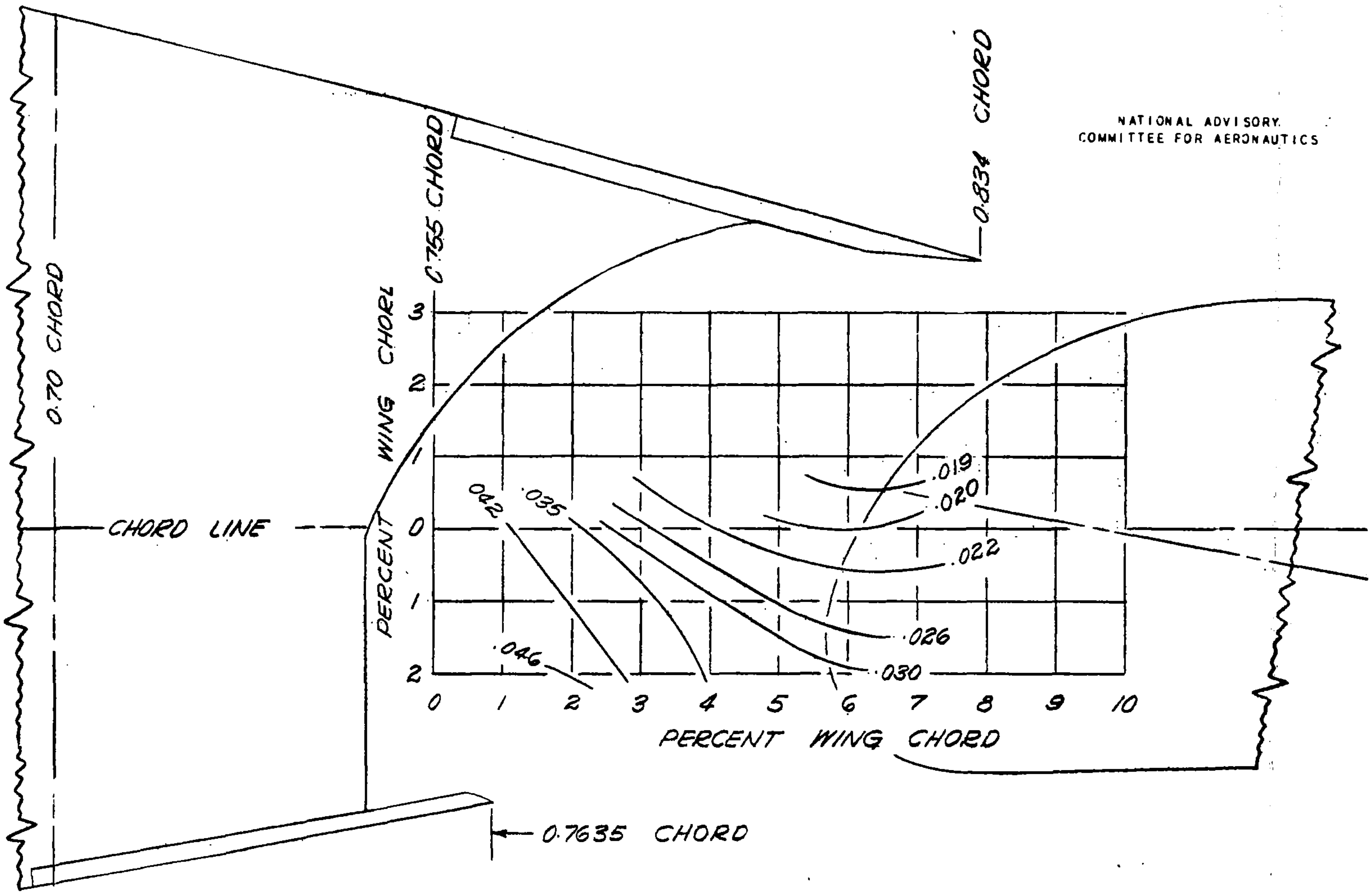
(d.) $\delta_f = 20°$, $c_l = 1.0$

FIGURE 6.- CONTINUED. NACA 66,2-216 (a=0.6) AIRFOIL EQUIPPED WITH THE 0.25-CHORD SLOTTED FLAP.



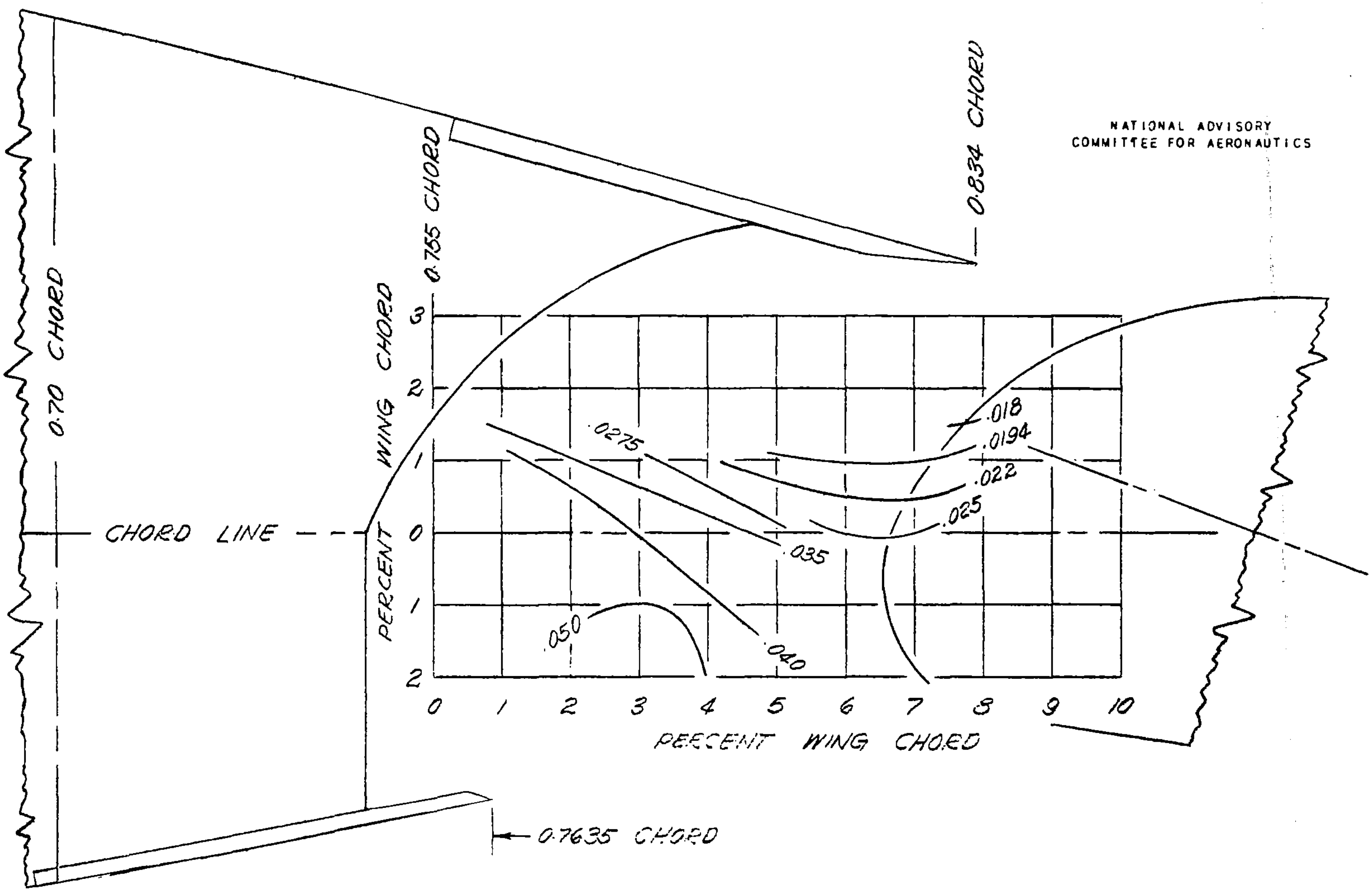
(e.) $\delta_f = 30°$, $c_l = 1.0$

FIGURE 6.- CONTINUED. NACA 66,2-216 (a=0.6) AIRFOIL EQUIPPED WITH THE 0.25-CHORD SLOTTED FLAP.



(f.) $\delta_f = 10°$, $c_l = 1.5$

FIGURE 6.- CONTINUED. NACA 66,2-216 (a=0.6) AIRFOIL EQUIPPED WITH THE 0.25-CHORD SLOTTED FLAP.



(g) $\delta_f = 20°$, $c_l = 1.5$

FIGURE 6.– CONTINUED. NACA 66,2-216 (a=0.6) AIRFOIL EQUIPPED WITH THE 0.25-CHORD SLOTTED FLAP.

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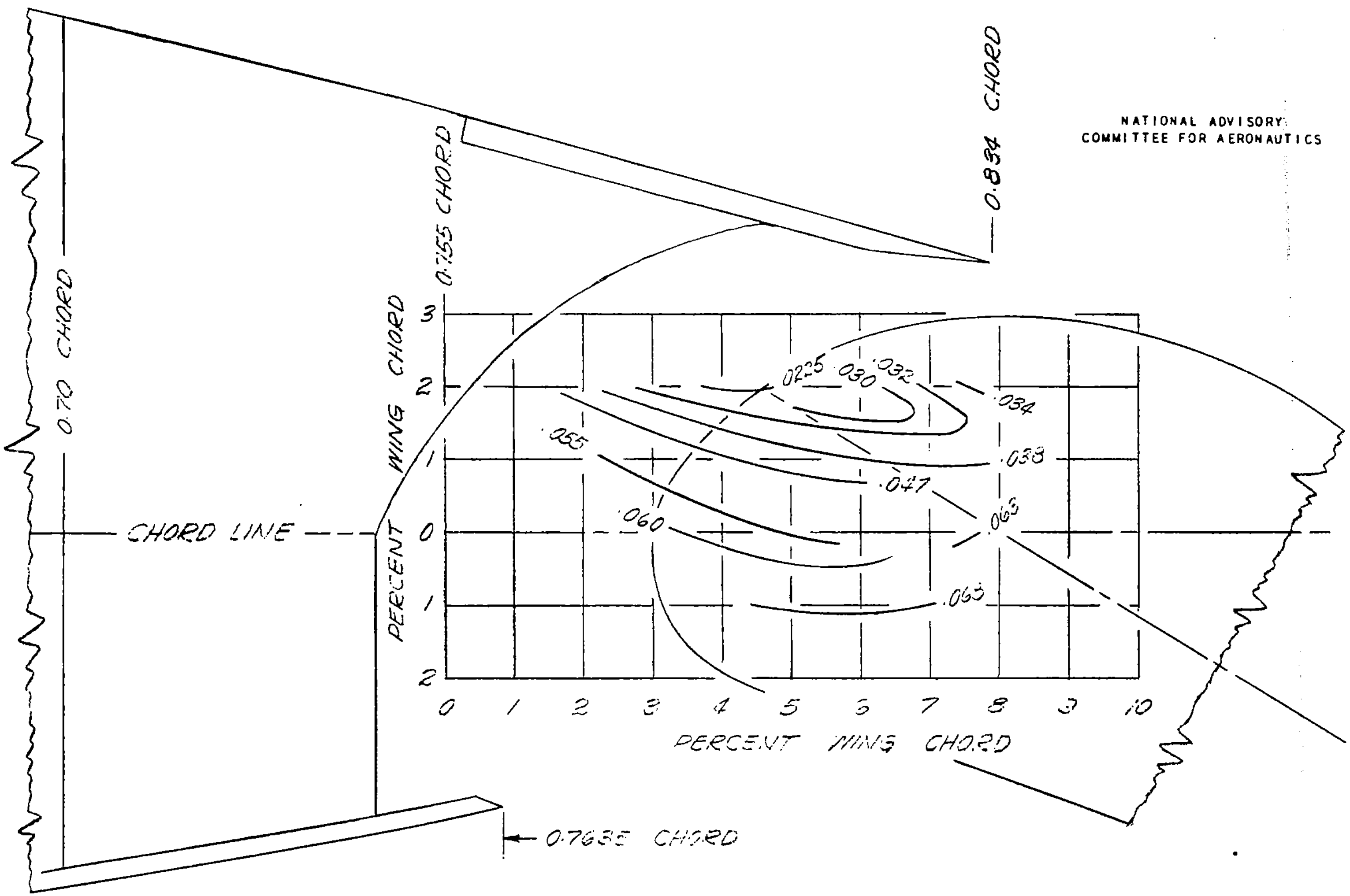
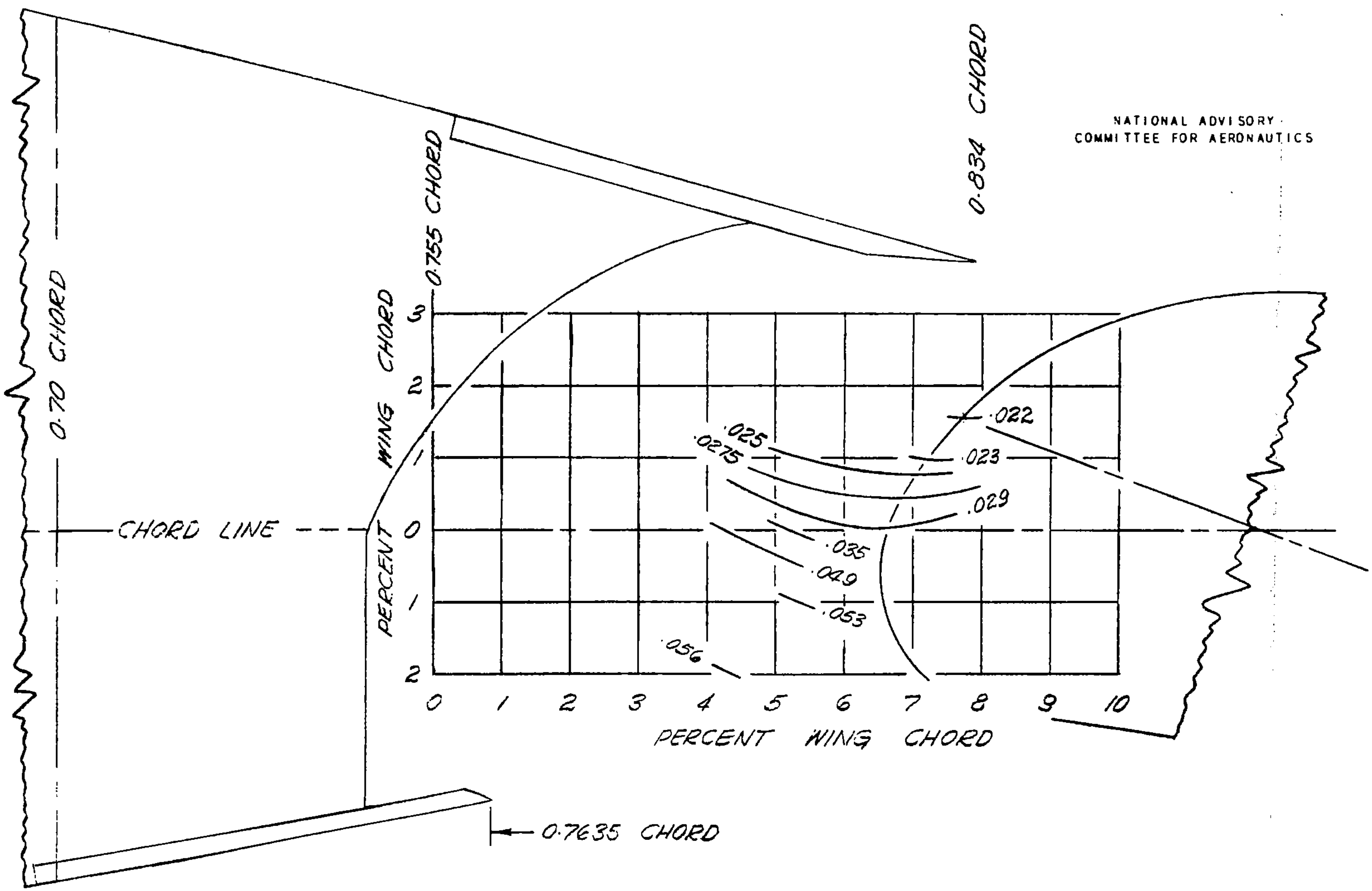


(h.) $\delta_f = 30°$, $G = 1.5$

FIGURE 6.- CONTINUED. NACA 66,2-216 (a= 0.6) AIRFOIL EQUIPPED WITH THE 0.25-CHORD SLOTTED FLAP



(i.) $\delta_f = 20°$, $c_l = 2.0$

FIGURE 6.- CONTINUED. NACA 66,2-216 (a=0.6) AIRFOIL EQUIPPED WITH THE 0.25-CHORD SLOTTED FLAP.

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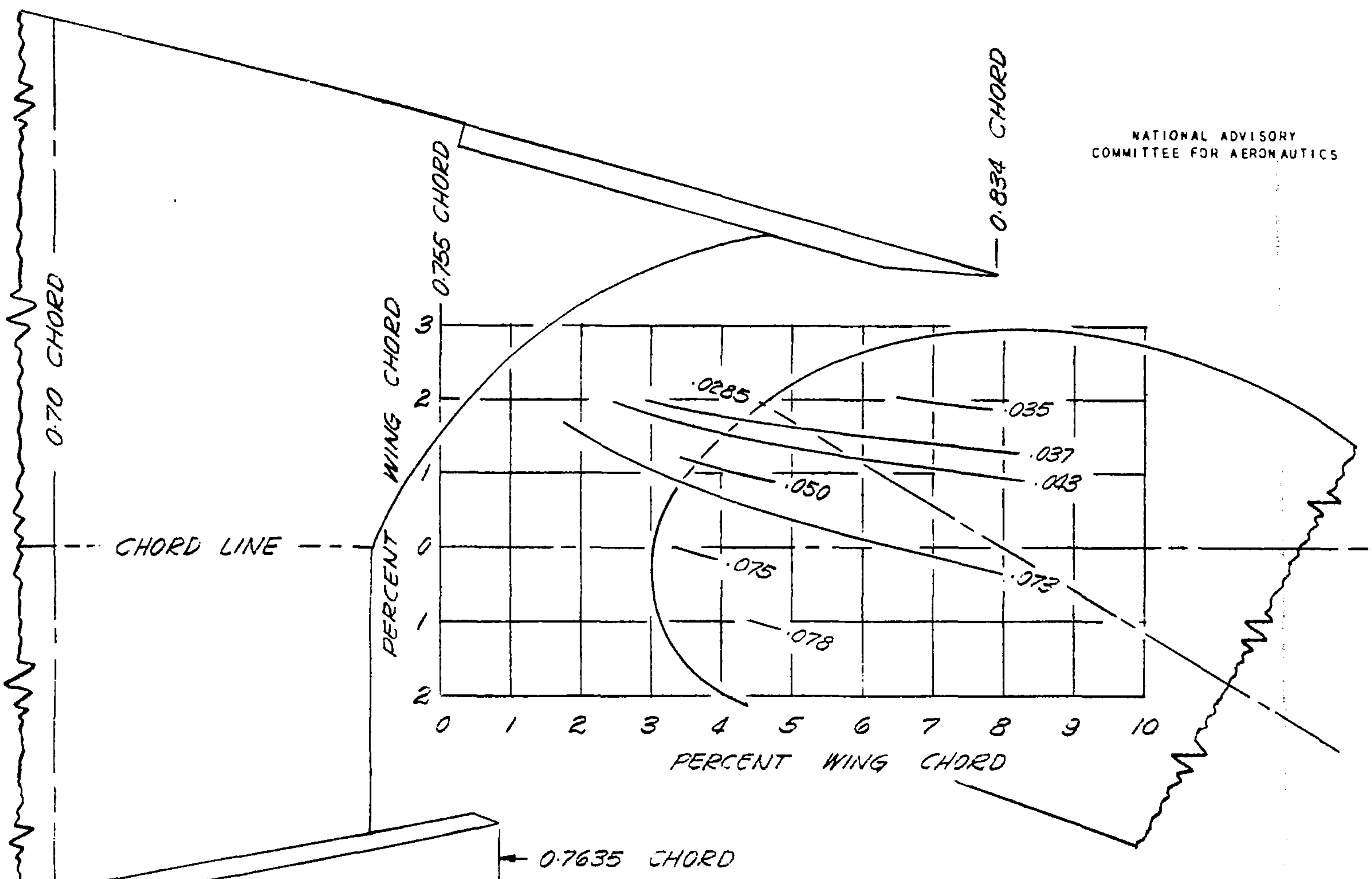

(j.) $\delta_f = 30°$, $c_l = 2.0$

FIGURE 6.- CONTINUED. NACA 66,2-216 (a=0.6) AIRFOIL EQUIPPED WITH THE 0.25-CHORD SLOTTED FLAP

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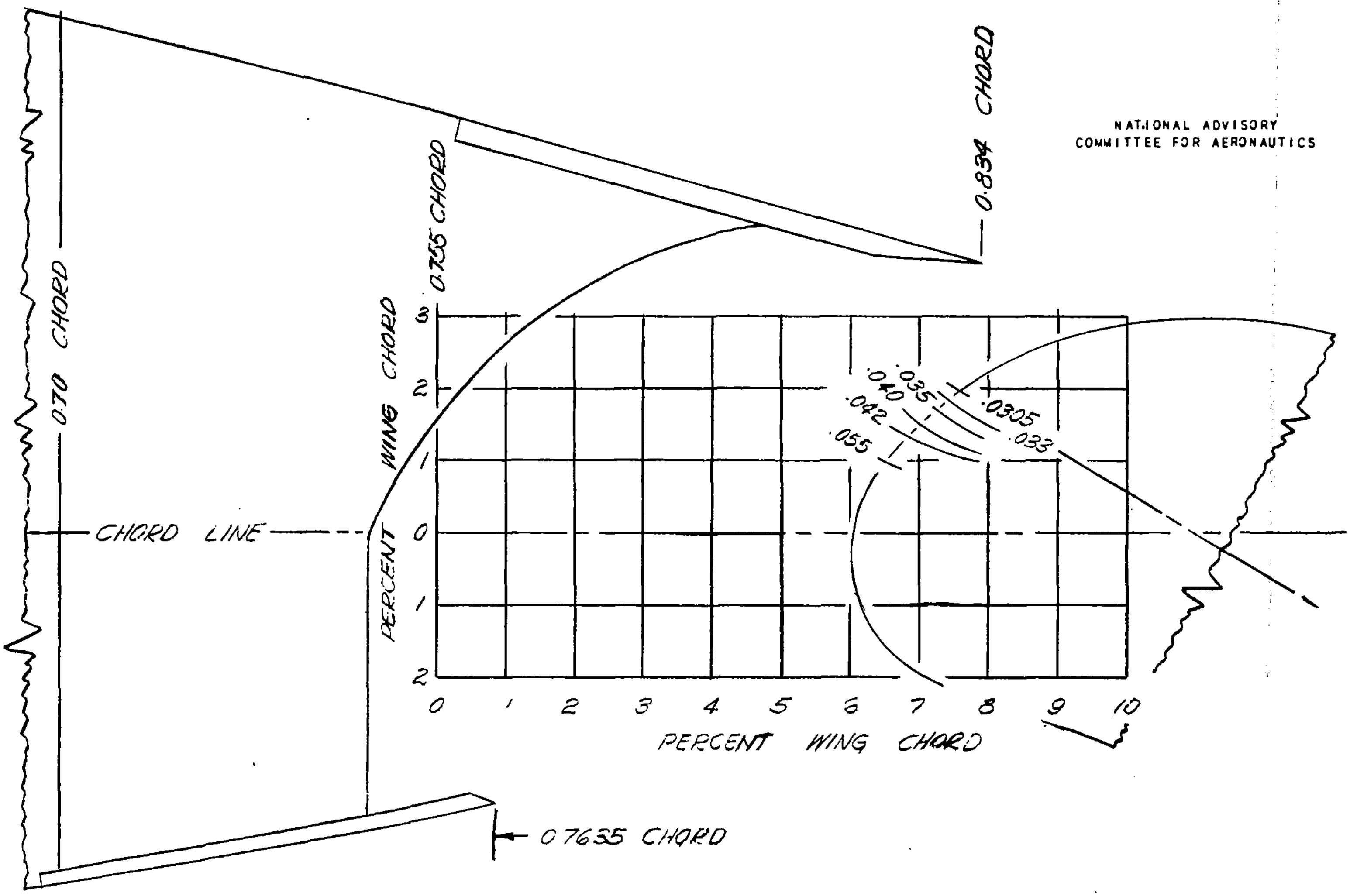

(k.) $\delta_f = 30°$, $c_l = 2.5$

FIGURE 6.- CONCLUDED. NACA 65,2-216 (a=0.6) AIRFOIL EQUIPPED WITH THE 0.25-CHORD SLOTTED FLAP.

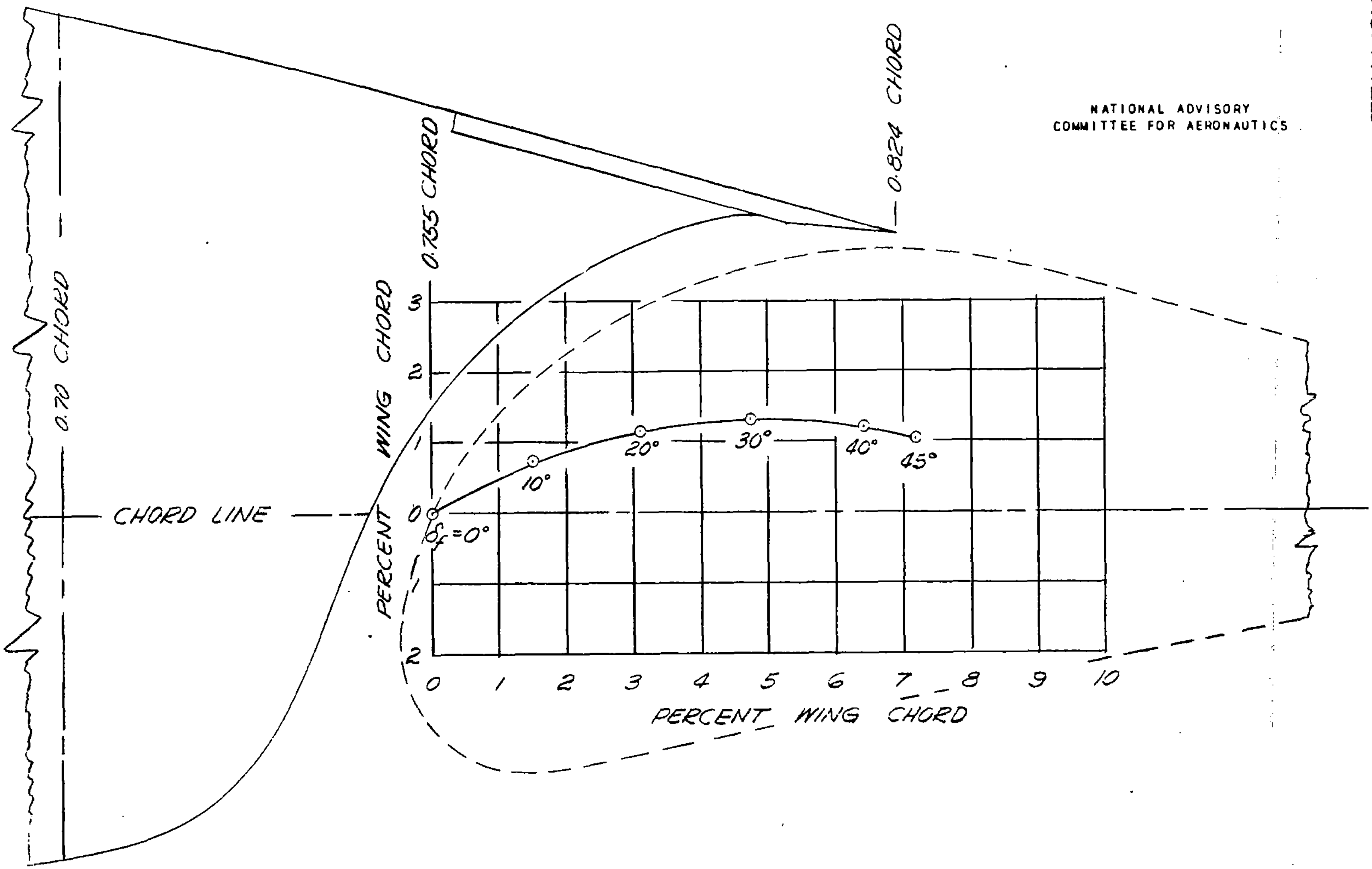

FIGURE 8.- THE FLAP PATH FOR THE 0.25-CHORD FLAP ON THE NACA 66,2-216 (a=0.6) AIRFOIL WITH SLOT A

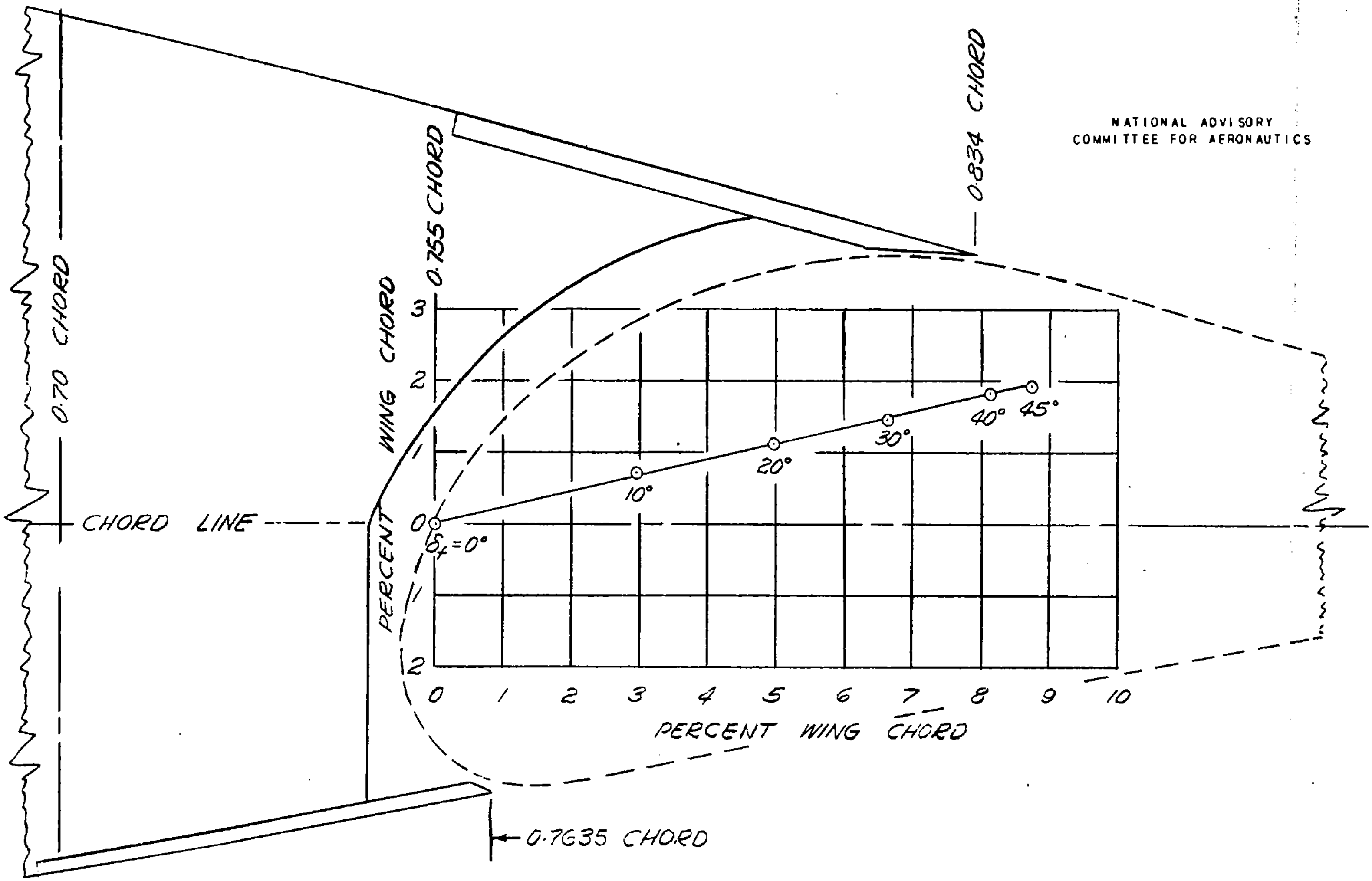

FIGURE 10.- THE FLAP PATH FOR THE 0.25-CHORD FLAP ON THE NACA 66,2-216 (a=0.6) AIRFOIL WITH SLOT B

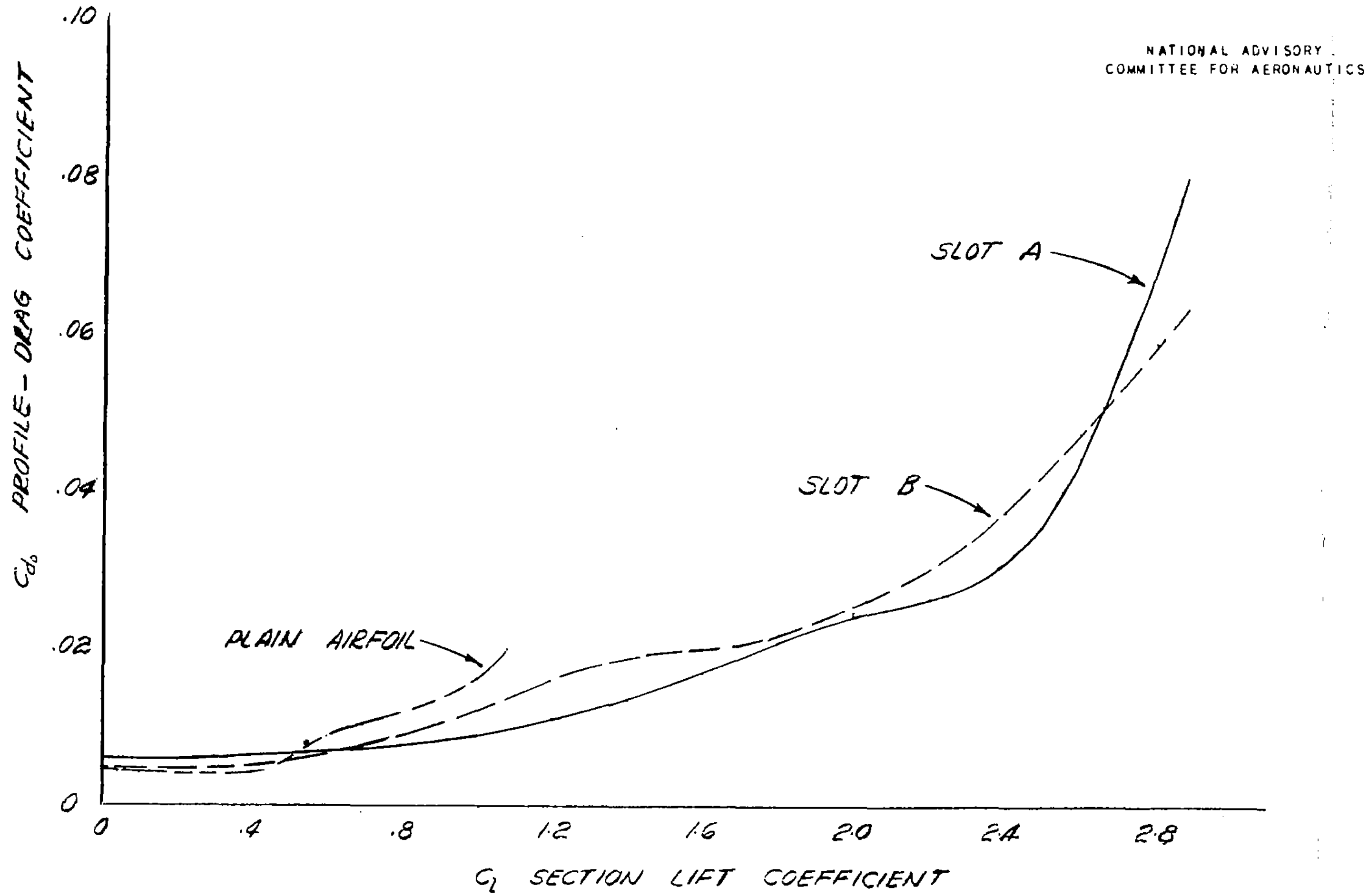

FIGURE 11.- ENVELOPE POLARS FOR THE FLAP PATHS SELECTED FOR THE TWO SLOTS TESTED ON THE NACA 66,2-216 (a = 0.6) AIRFOIL EQUIPPED WITH THE 0.25-CHORD FLAP

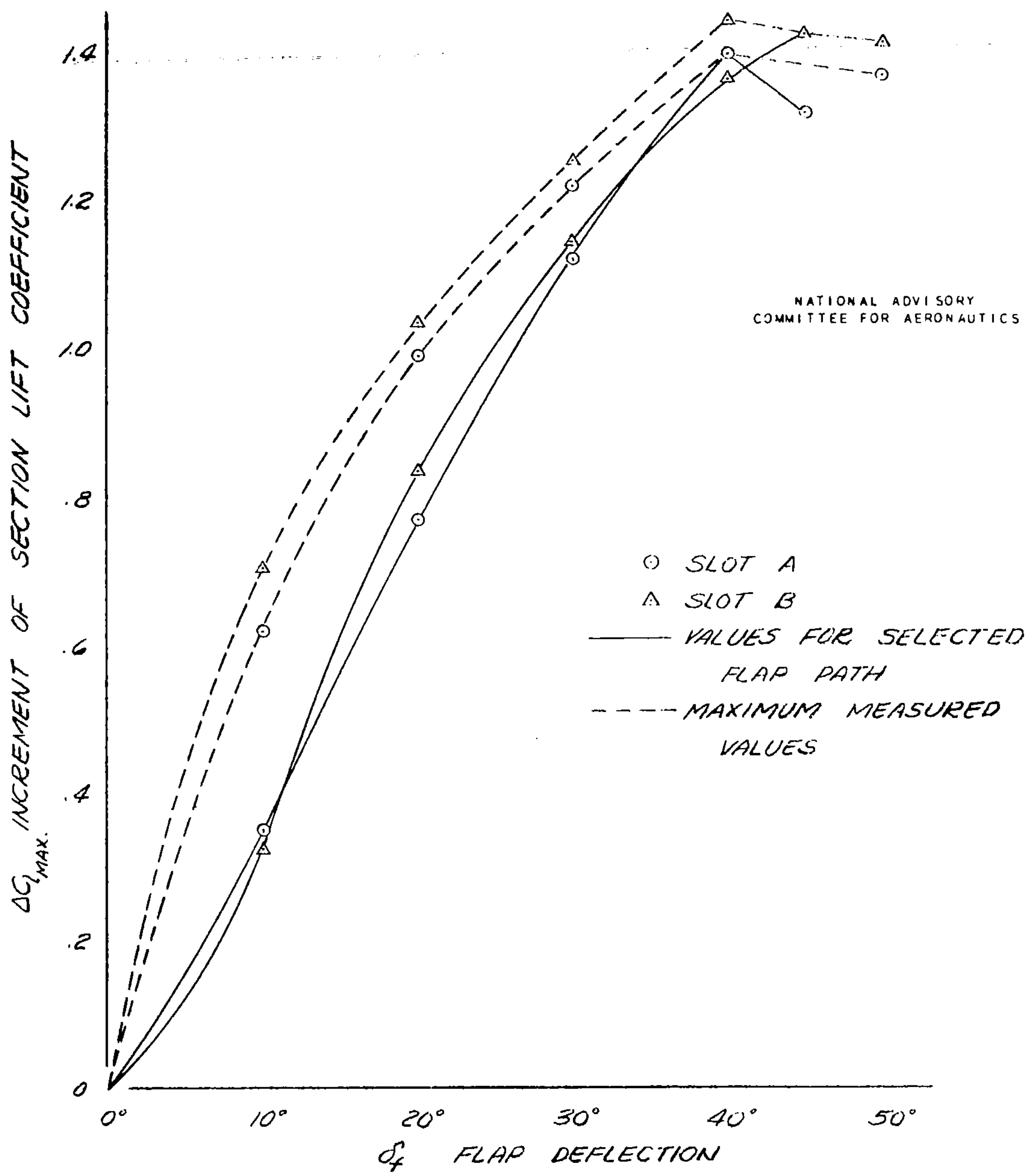

FIGURE 12.- INCREMENT OF MAXIMUM SECTION LIFT COEFFICIENT DUE TO FLAP DEFLECTION FOR THE NACA 66,2-216 (a = 0.6) AIRFOIL EQUIPPED WITH THE 0.25-CHORD FLAP

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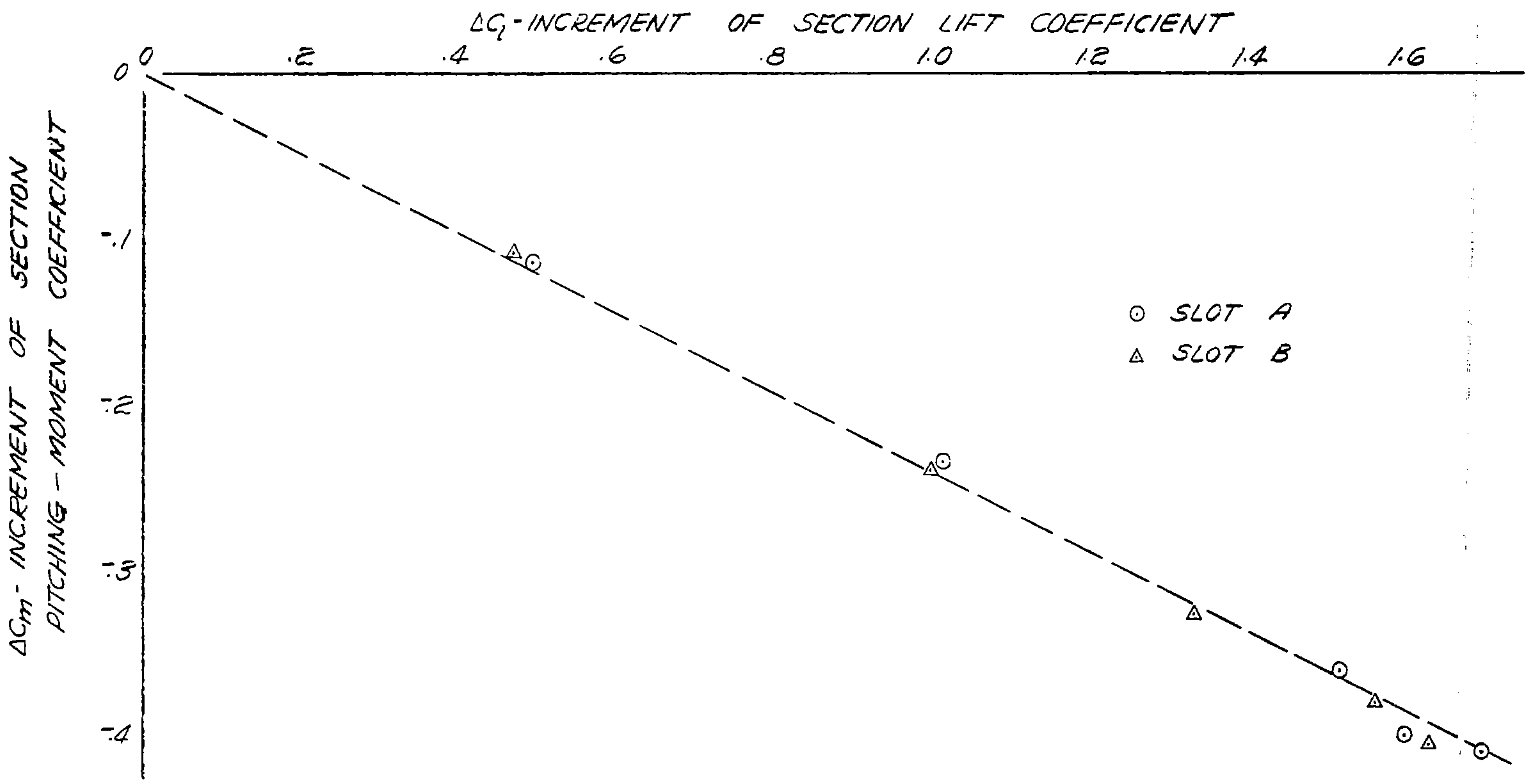

FIGURE 13.- THE VARIATION OF THE INCREMENT OF SECTION PITCHING-MOMENT COEFFICIENT WITH THE INCREMENT OF SECTION LIFT COEFFICIENT DUE TO DEFLECTION OF THE 0.25-CHORD FLAP ALONG THE SELECTED FLAP PATHS ON THE NACA 66,2-216 (a=0.6) AIRFOIL $\alpha_0=0°$